NAL PROPOSAL No. 0051

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MASS SPECTRUM AND DECAY MODES FOR BOSONS IN THE 2.0 TO 8.6 Gev/c^2 MASS RANGE

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June 15, 1970

NORTHEASTERN UNIVERSITY

BOSTON, MASSACHUSETTS 02115

DEPARTMENT OF PHYSICS

October 5, 1970

Dr. F. T. Cole
Secretary, Program Advisory Committee
National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510

Dear Dr. Cole:

I'm writing you concerning an addition to the names of the experimenters listed on proposal 51 entitled "Mass Spectrum and Decay Modes for Bosons in the 2.0 to 8.6 Gev/c^2 Mass Range". We wish to add the name of Professor David Ritson of Stanford University.

Yours truly,

Marvin Gettner

Marvin Gettner

MG/bjc

cc: D. Ritson

PROPOSAL DISTRIBUTION
NOTE ON LOGS

The upper limit for the second missing mass m_b was lowered so that for the range of masses covered the contribution to the mass resolution Δm^2_b from measurement of the recoil proton would be less than that from the measurement of the fast forward pion. For all incident momenta below 80 Gev/c the lower limit to the mass range is essentially zero and the value of 0.5 for 24 Gev/c shown in the original table is an error. For the highest mass range it will be necessary to restrict the pion angle to achieve the desired resolution.

For the resolutions given above, boson decays of the type $\pi\pi$, $\pi\rho$, $\pi\omega$, πA, πf, can be identified. Although the ρ,ω and A,f, cannot be separated on the basis of their mass with this resolution, they can be distinguished by the presence or absence of accompanying γ-rays. For this purpose, the γ-ray detectors surrounding the target as mentioned in proposals 35 and 54 would be of great value in this experiment.

2. Magnet Size

The magnet size could be reduced from the 2m x 2m x 4m originally proposed. The major cost in reduction is a loss in counting rate for the decay mode type events. The 4m field length could be reduced to 3m with only a small effect on the resolution. The horizontal aperture could be reduced to 1m without affecting the acceptance desired in the c.m. for decays, but would reduce by a factor of two the decay event counting rates shown in Table I. The vertical aperture can be reduced at further expense to the counting rate.

The reduction in the vertical gap would severely reduce the efficiency for other types of decay modes where it would be desirable to track more than one particle through the magnet. For example, decays of the type $\rho^o + b$ and $\pi^- + b$, can be studied for events where two and three charged particles are tracked through the magnet.

The proposed "consensus" magnet would be very suitable for this experiment and would reduce the expected counting rates by only 25%.

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Northeastern University
High Energy Physics Group
11/5/71

Summary of Physics and Logistics

(Presented to the NAL-PAC 11/3/71)

(Experiment #51, 11/5/71 revision. Information, supplementary to information already provided, in association with proposals #51 and #140.)

Primary Physics Goals

The main goal of our measurements is to search for and measure the quantum numbers of high mass ($2 \leq M \leq 10$ GeV) hadron states using all techniques available in the proposed apparatus. At a minimum this means using single and double missing mass as well as effective mass techniques. The study of the production dynamics of known resonances will not be a primary goal in the experiment. However, the final data will be examined for dynamical effects and will provide useful information about inclusive reactions, etc. at high energies.

More specifically, we propose to accumulate approximately 2×10^7 events with excellent single missing mass, double missing mass, and effective mass resolutions. These studies are a continuation, to higher energies and more complete measurements of the events, of an experiment we recently completed at the Brookhaven AGS (in collaboration with SUNY at Stony Brook) which examined the $0.1 \leq M \leq 2.7$ GeV region.

Reactions to be Studied*

(a) $\pi^- p \rightarrow \pi^{-*} \underline{p}$

(b) $\pi^- p \rightarrow \pi^{-*} \underline{p}$

$\quad \rightarrow \underline{\underline{\pi^-}}\ b^o$ (b1)

$\quad \rightarrow \rho^o\ b^-$, $\rho^o \rightarrow \underline{\underline{\pi^-}}\,\underline{\underline{\pi^+}}$ (b2)

$\quad \rightarrow A_2^-\ b^o$, $A_2^- \rightarrow \underline{\underline{\pi^-}}\,\underline{\underline{\pi^-}}\,\underline{\underline{\pi^+}}$ (b3)

$\quad \rightarrow$ etc. (b4)

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*Single underlines indicate particles detected in the proton spectrometer; double underlines indicate particles detected in forward spectrometer; triple underlines indicate particles detected in a cylindrical range detector.

(c) $\pi^- p \to \pi^{-*}$ + (anything) (c1)
all charged

$\to b^{o*}$ + (anything) (c2)
all charged

(d) $\pi^+ d(n,p) \to (b^o)^*\ \underline{p}\ p_s$

p_s is spectator proton which does not escape H_2 tgt.

all charged (d1)

(e) π^- nucleus $\to (\pi^-)^*$ + (anything)
all charged (e1)

$\to (\pi^-)^*\ \underline{p}\ \underline{p}$+ (anything)
all charged (e2)

The analogus reactions, (a') → (e'), using incident protons will also be studied. However, the analysis of the proton events might be more formidable since no $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ separation will be made of the particles detected in the forward spectrometer.

Reactions (a) and (b1) represent the single and double missing mass measurements which are extensions to higher energies of our BNL measurements. The detected proton provides the "high mass" trigger. Since the forward spectrometer (unlike the forward spectrometer used at BNL) has a large acceptance, effective mass spectroscopy will also be carried out.

Reaction (d) studies neutral high mass objects which decay into charged particles. The detected proton provides the high mass trigger and the requirement that the number of charged particles leaving the hydrogen be an odd number insures that the H^* (H = hadron) production took place from the target neutron via $Hn \to H^*\ p$.

Reactions (e1) and (e2) will be studied to examine H^*'s which require two single nucleon collisions in order to be made with appreciable cross sections, for example

$$\pi^- \mathrm{Nuc}(p,p,\ldots) \to (A_2^-\ \mathrm{Nuc}(,p,\ldots)) \to (A_2^{-*}\ \mathrm{Nuc}(,,\ldots))$$
all charged

The trigger, in this case, will be two slow protons coming out of a heavy nuclei target, or a broader trigger to detect stars.

The major protion of the experiment will study reactions (a), (b), (a'), and (b') and less than one-third of the data time will be devoted to the less established methods (c,c'), (d,d') and (e,e').

Apparatus

We proposed to study reactions (a) → (d) and (a') → (d') with an apparatus similar to that indicated in Figs. 1 and 2 using a hadron beam of 10^5 particles per pulse (1 sec spill). At this rate, even those spark chambers directly in the incident beam should have a tolerable number of background tracks, even with no dead spots for the incident beam. (The beam is discussed in detail, below, in the Beam Logistics section).

The proton spectrometer shown in Fig. 1, except for the detectors immediately adjacent to the H_2 target (cylindrical proportional chamber and decay hodoscopes) is the one used in our BNL-AGS experiment. The forward spectrometer uses spark chambers and scintillation hodoscopes as detectors.

Hodoscopes and spark chambers almost identical in active areas and spatial resolution to these needed for our experiment are currently being constructed by the Muon-Proton Inelastic Scattering Experiment Collaboration (Chicago, Harvard, Oxford Collaboration). We are presently exploring the possibility of using some of the equipment constructed by the μp Collaboration. However, if this is not practical, we would ourselves construct the detectors shown in Fig. 2.

Run Plan, Event Rates, Sensitivities to Resonances, and Mass Resolutions

The run plan, event rates and mass resolutions are given in Table 1. In arriving at the data rates, we have assumed a conservative system dead time, for both the proton and forward spectrometer being pulsed, of 50 m sec/event. The calculated coincidence trigger rate, at 10^5 in the incident beam, is $\sim$ 25 m sec/trigger and the proton spectrometer will be pulsed at this rate. The effective mass trigger rate, reactions (c), (c'), (e) and (e') should be very large, approximately 0.2 m sec/trigger. Thus, during the effective mass trigger runs, specific topologies will be selected in the trigger, based on the number of charged particles observed by the forward spectrometer, so that the more interesting rare topologies can be studied in detail.

The experiment's sensitivity to resonances is approximately 10^3 events/μ barn for each 100 hours of data collection time. The actual signal to noise ratios for resonance production is difficult to estimate but is expected to be for "narrow" resonances (i.e. resonances where Γ experimental $\geq \Gamma$ physical), for single missing mass data with no data cuts, signal: noise $\sim$ 1:20 for σ (resonance) $\simeq$ 5 μ barns, and for double missing mass, specific topologies (for example $p\pi^-\pi^o$ final states, i.e. resonances decaying into $\pi^-\pi^o$) signal:noise $\sim$ 2:1 for σ(resonance) $\sim$ 5 μ barns. These estimates are based on a simple extrapolation of our BNL results to higher energies.

Beam Logistics and Beam Scheduling

The beams, parameters of which are indicated in Table I, have been designed to be compatible with the beams used in both the narrow band and broad band ν experiments. All apparatus debugging, calibrations, and all proton data can be recorded when the broad band ν experiments are running. This will require the extraction of $\sim$ 6 x 10^{11} (or $\sim$ 2% of the NAL design intensity) protons onto the ν experiment target, for $\sim$ 1 sec, after the short spill ν pulse has taken place. Only the π data will require the narrow band ν front end (maximum of 600 hours of data taking), and can be carried out in less than three calendar months.

We can set up the experiment in one month, debug the apparatus and record the proton data in the next three calendar months, while either the narrow band or broad band experiments are running, and then record the π data, during a narrow band ν experiment, in the final three calendar months of the experiment. (We have assumed that the narrow band ν experiments will operate with the first stage of the beam set to 100 GeV, P(primary) $\simeq$ 200 GeV, for at least 400 hours and set to 200 GeV, P(primary) $\sim$ 400 GeV, for at least 200 hours during our π^- runs.)

Availability of Equipment and Manpower to Carry Out Experiment

Assuming the large spark chamber and hodoscopes can be borrowed from the μp Collaboration, we can prepare the remaining equipment and computer software by January 1973 and complete the experiment by [redacted] August 1973, providing the necessary beam time specified in Table I is available during this time.

If this experiment is scheduled and begun on or before January 1974 it will be the dominant research effort, and only major experiment, in which our group is involved. We expect that approximately 10 Northeastern University physicists will make this experiment their sole research effort. Three of these physicists are expected to be full time research associates with no teaching responsibilities. If NAL, at this time, approves and schedules this experiment to run prior to January 1974, we request that Proposal #140 be no longer considered active.

Other Requirements etc.

It is hoped that other requests and requirements (for example computer time and electronics requests) previously conveyed to NAL concerning Proposals #51 and #140, along with the proposals themselves, have provided enough details so that the PAC and NAL staff can make a decision on this experiment at this time.

TABLE I (1 of 4 pages)

Run Plan, Event Rates, and Mass Resolutions

Symbol definitions; typical reactions i) $\pi^- p \rightarrow \pi^{-*} \underline{p}$, $\pi^{-*} \rightarrow \underline{\underline{\pi}}^- b^o$ ii) $pp \rightarrow (p)^* \underline{p}$, $(p)^* \rightarrow \underline{\underline{p}}\, b^o$

	Beam Particle	Beam Momentum (GeV)	Reactions Studied	Secondary Beam Configuration*
1)	π^-	100	(a), (b)	NB ν
2)	π^-	200	(a), (b)	NB ν
3)	π^-	100	(c),(d),(e)	NB ν
4)	p	100	(a'),(b')	BBν or NBν
5)	p	200	(a'),(b')	BBν or NBν
6)	p	100	(c'),(d'),(e')	BBν or NBν

*NBν is the NAL Muon Beam No. N1 with the narrow band neutrino beam No. c Phase I first stage and has $\Delta p/p \sim 0.2\%$, $\Delta\Omega \sim 13$ μ strad.

BBν is identical to the NBν beam except the first stage is the NAL broad band ν beam first stage which will be run to have $\Delta p/p \sim 0.2\%$, $\Delta\Omega \sim 10^{-2}$ μ strad.

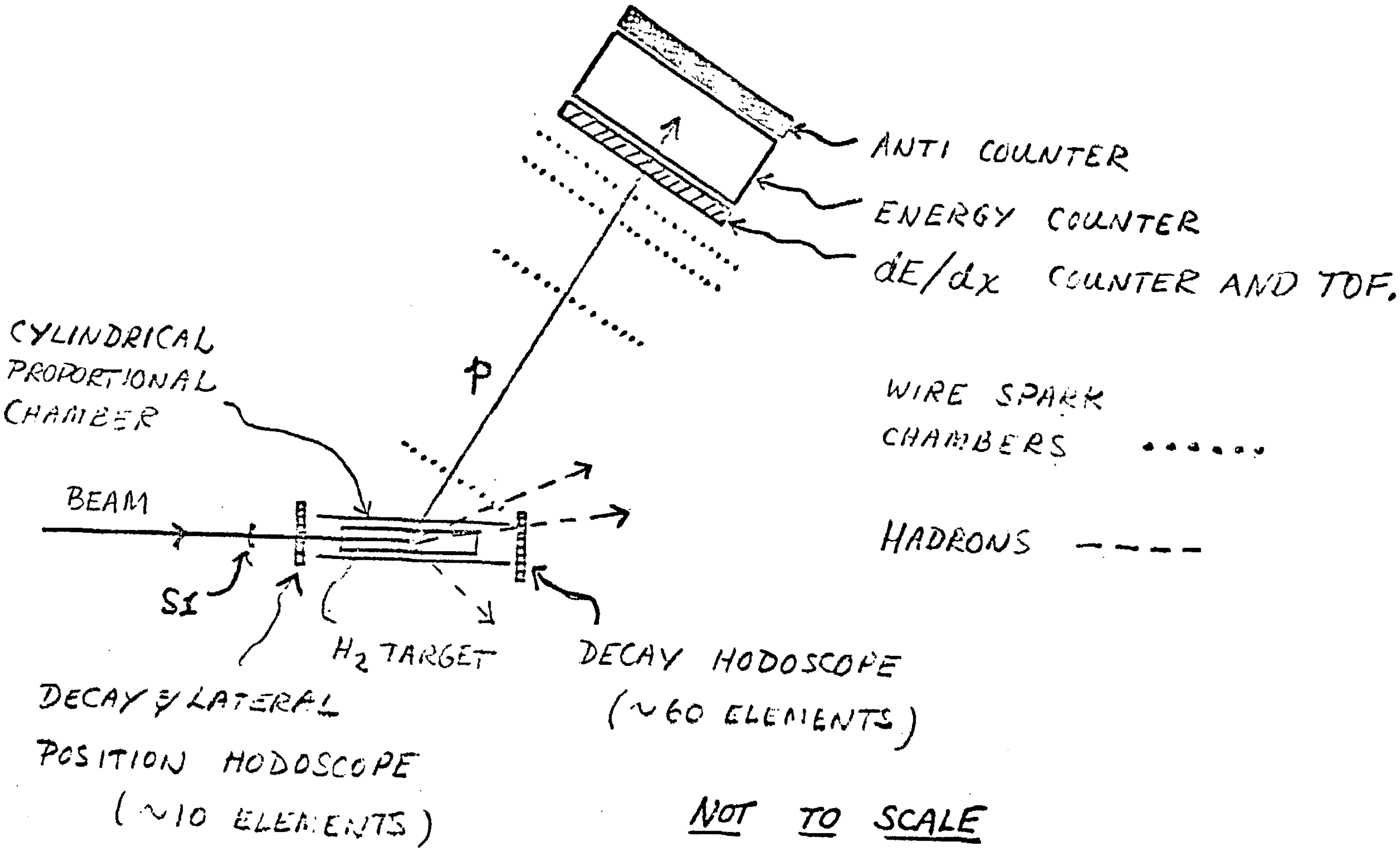
	Secondary Beam Flux	Primary Proton Beam Configuration† (GeV; particles per pulse from accelerator)	$M^2((\pi^-)^*$ or $(p)^*)$ Range $(GeV)^2$
1)	10^5	200; 10^{12}	0-50
2)	10^5	400; 3×10^{11}	0-100
3)	10^5	200; 10^{12}	0-50
4)	10^5	200; 10^{12}	1-50
5)	10^5	200; 6×10^{11}	1-100
6)	10^5	200; 6×10^{11}	1-50

†This configuration assumes that the primary proton beam's focus at the production target is $1mm^2$ at 400 GeV and $4mm^2$ at 200 GeV. For the π^-'s, flux curves of C. L. Wang (BNL 15893) are used. These curves are considered conservative since the predicted yields are approximately a factor of five lower than the predictions of Trilling. For the π^- beams $1/6 \times (P_p/400)^2$ of the protons are assume to interact in a $1mm \times \frac{1}{2}mm \times 1$ nuclear free path production target. The proton fluxes used are those given by D. Garelick, Phys. Rev. Lett. 22, 674 (1969).

	$M^2((\pi^-)^*$ or $(P)^*)$ Resolution (fwhm,GeV^2) (single missing mass)	$M^2_{b^o}$ Resolution (fwhm,GeV^2) (double missing mass)	Effective Mass (M_E) Resolution ($\delta M/M$,%,fwhm)
1)	1.0	final state $p\pi^-\pi^o$;0.25	M_E = 0.75; 2%
		" " $pA_2^-b^o$;0.15	M_E = 2.7; 1%
2)	2.0	" " $p\pi^-\pi^o$;0.50	M_E = 0.75; 4%
		" " $pA_2^-b^o$;0.30	M_E = 5.5; 2%
3)	1.0		
4)	1.0	final state $pp\pi^o$;0.25	M_E = 2.7; 1%
		" " $pp\omega^o$;0.25	
5)	2.0	" " $pp\pi^o$;0.50	M_E = 5.5;2%
		" " $pp\omega^o$;0.50	
6)	1.0		M_E = 2.7;1%

	Data Collection Time(hours)	Total Events
1)	200	4×10^6
2)	200	4×10^6
3)	200	4×10^6
4)	200	4×10^6
5)	200	4×10^6
6)	200	4×10^6

TARGET REGION

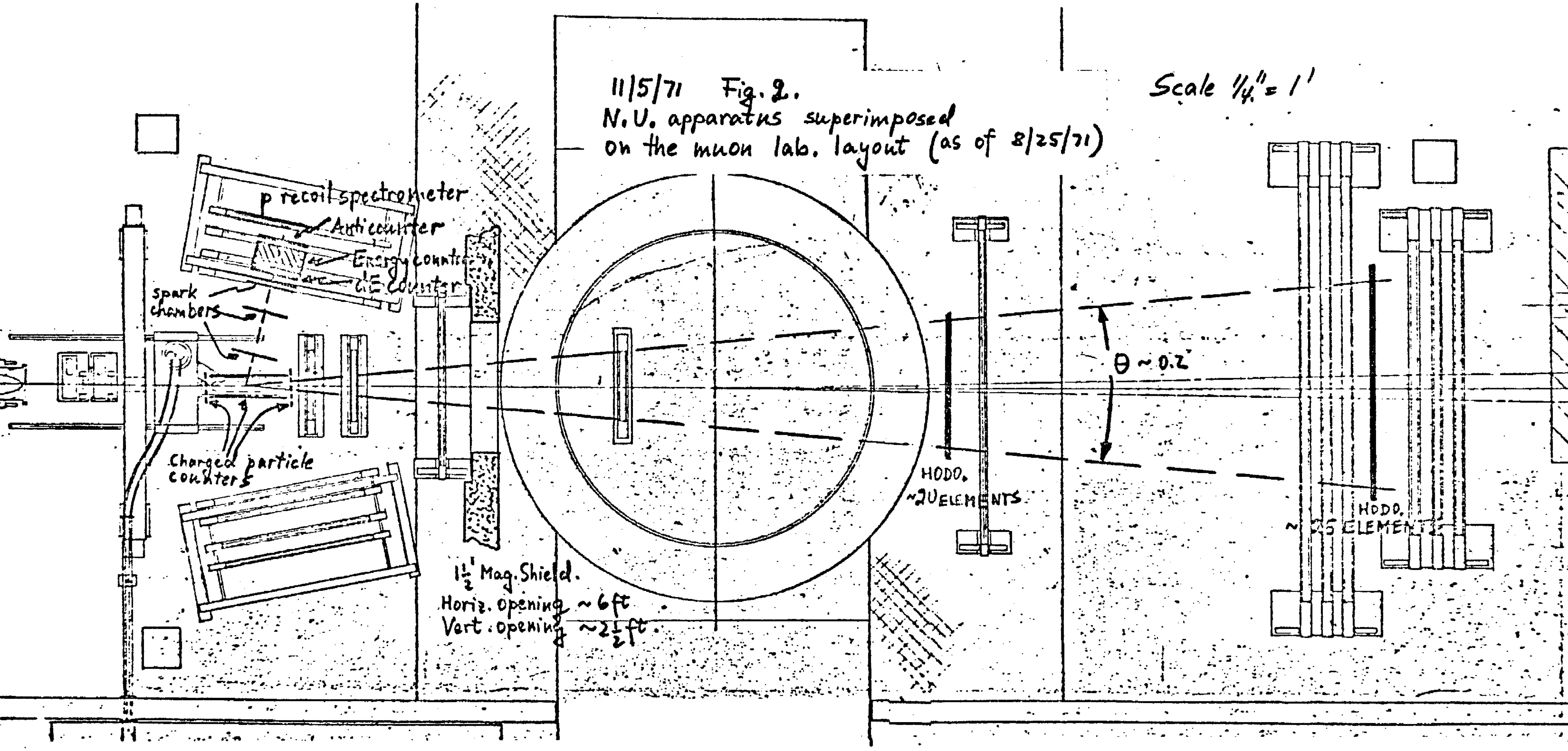


NOT TO SCALE

FIG. 1

11/5/71 Fig. 2.
N.U. apparatus superimposed on the muon lab. layout (as of 8/25/71)

Scale 1/4" = 1'



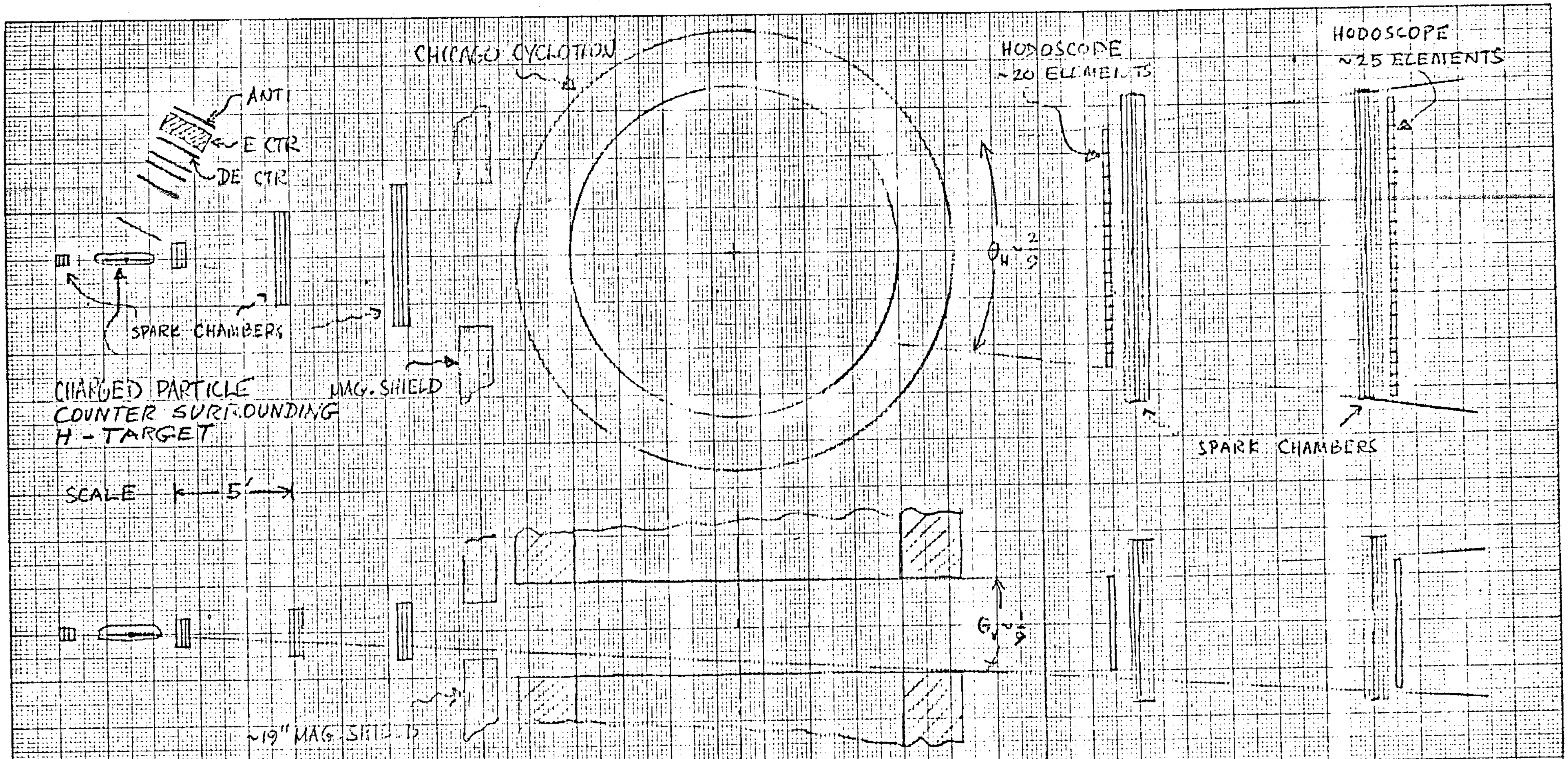


FIG. 3 TOP- AND SIDE VIEW OF N.U. LAYOUT.

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November 22, 1970

To: R. R. Wilson

From: M. Gettner
Physics Department, Northeastern University

Subject: Revision of Proposal #51

As a result of the Multiparticle Spectrometer Workshop held October 29 - 30 we wish to revise proposal 51 as follows:

1. 80 Gev/c Beam and Two Body Boson Decay Modes

The highest beam momentum available for this experiment now appears to be 80 Gev/c instead of the 96 Gev/c mentioned in the proposal. This will not significantly change the scope of the experiment. The mass range and resolution shown in Table I of the proposal for 96 Gev/c should be reduced by ~ 8% for the lower momentum.

In addition the entries in Table II for the 96 Gev/c beam have been recalculated for 80 Gev/c. A revised table is shown below. The numbers in this table for 24 and 48 Gev/c differ slightly from those in the original proposal.

Table II (Revised)

Mass Range and Resolution for the Second Missing Mass in the Reaction $\pi^- + N \rightarrow N + B$

$\rightarrow \pi + b$

E_B Beam Energy	m_B First Missing Mass	m_b Second Missing Mass	$\frac{\delta P_\pi}{P_\pi}$ Resolution of Fast pion	Δm_b^2 Second missing mass resolution
24	2.5	.1 - 1.94	± .5%	.12
48	3.5	.1 - 2.71	± .5%	.24
80	4.4	.1 - 3.41	± .8%	.32

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Addendum to Proposal #51

NORTHEASTERN UNIVERSITY

BOSTON, MASSACHUSETTS 02115

DEPARTMENT OF PHYSICS

November 10, 1971

Dr. R. R. Wilson and Members of the PAC
National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510

Gentlemen:

As we have indicated in our letter of October 12 to Dr. Wilson, and in our discussions at the PAC meeting at NAL on November 3, we are prepared to carry out the measurements defined in proposal #51.

As discussed in detail in the enclosed material, we can carry out proposal #51 using a "converted" μ beam and the Chicago cyclotron magnet. After careful study, we are confident that the conversion of the μ beam to a high quality hadron beam will not require a large effort. More specifically, we have designed two hadron beams, both of which use only existing μ beam magnets and enclosures. One beam is a π^- beam that is compatible with the NAL narrow band ν beam and the other beam is a secondary proton beam which is compatible with both the narrow band and broad band ν beams. Both beams require only $\sim 10^{12}$ protons from the accelerator. We can carry out most of the experiment (debugging, testing, and proton data) in a mode that is compatible with both the broad and narrow band ν programs.

We have also investigated the compatibility of our proposed detector system with that of the NAL μp Collaboration and found that the incompatibilities between the two experiments are minimal. In fact, we are most willing to make use of many of the detectors that will be used in the μp experiment, especially the large spark chambers.

We hope that the detailed information that we have previously supplied (NAL proposal #51 and revisions 9/22/70, and NAL proposal #140 and additional details, letter to J. Sanford 8/3/71) along with the enclosed information have provided sufficient descriptions of the experiment.

One of us (EvG), a senior member of our research group, has arrived at NAL to spend one year, full time, at NAL in order to provide a liason between NAL and our group. We hope that this full time presence at NAL plus the part time presence of other senior people in our group will allow our experiment to proceed at the maximum rate possible.

In summary, we believe that our physics is of great interest, that we have previously demonstrated our capability to carry out such an experiment, and that our requests for accelerator time, intensity and equipment are reasonable. We hope an approval of the experiment is possible in the very near future.

If we can provide any further information or be of help in any way, kindly let us know.

Eberhard von Goeler
Eberhard von Goeler

David Garelick
David Garelick

Marvin Gettner
Marvin Gettner

Roy Weinstein
Roy Weinstein

cc: J. Sanford

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N. A. L. PROPOSAL

June 15, 1970

Mass Spectrum and Decay Modes for Bosons in the 2.0 to 8.6 Gev/c^2 Mass Range.

A "double" missing mass spectrometer experiment is proposed to study the mass spectrum of non strange and strange bosons produced in the reactions $\left\{ \begin{matrix} \pi^- \\ K \end{matrix} \right\} + N \rightarrow N + B$ where the B mass ranges from 2.0 to 8.6 Gev/c^2. In the 2.0 to 6.0 Gev/c^2 range both neutral and charged bosons will be studied and systematics of decays of the type $B^{\overset{-}{0}} \rightarrow \pi^{\overset{-}{+}} + b^{\overset{0}{+},-}$ will be obtained.

Submitted by

D. Bowen, D. Earles, W. Faissler, D. Garelick, M. Gettner, B. Gottschalk, G. Lutz, E. Shibata, E. von Goeler, and R. Weinstein

Northeastern University, Boston, Massachusetts

and

H. R. Bleiden

State University of New York at Stony Brook

Correspondent: M. Gettner

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I. Description of the Experiment

An experiment is proposed to study bosons in the 2.0 to 8.6 GeV/c^2 mass range by means of a "double missing mass spectrometer". Bosons produced in the reaction $\pi^- + N \rightarrow N + B^-$ will be "tagged" by recoil nucleon spectrometers, while a decay spectrometer will detect, in coincidence with the proton, fast pions from boson decays of the type $B \rightarrow \pi + b$. In this way both a mass spectrum of produced bosons and a mass spectrum for two body decays by single pion emission will be obtained. This apparatus combines the high data rates and good mass resolution of the usual missing mass proton spectrometer with the ability to determine decay modes.

This is a continuation of an experiment now in operation at Brookhaven, where the 1 to 5 GeV/c^2 mass range is being studied. Much of the apparatus now in operation will be applicable to N.A.L.

The major aims of the experiment are:

1. High Mass Search For Charged Bosons

We proposed to explore the 4 to 8 GeV/c^2 mass range. For bosons produced with a total cross section of 10 μb, we would get 30,000 events above background for each new peak per 10^6 pions per pulse for 40 hours of beam time. The range would be explored by measuring proton recoils in the forward direction to obtain the optimum mass resolution. With the spectrometer in this configuration no decay information is expected. For the proton detector presently operating at BNL, a mass resolution of 30 to 60 MeV/c^2 would be obtained at N.A.L. for the 4 to 8 GeV/c^2 range.

2. Decay Modes

We propose to study the two body decay modes of charged and neutral bosons in the 2 to 5 GeV/c^2 range. Charged bosons will be tagged by a proton recoil spectrometer, while the neutral bosons will be tagged by a neutron recoil spectrometer. Both spectrometers will be operated in the Jacobian peak region.

The decay spectrometer is particularly suited for boson decays of the type

$$B^{\bar{o}} \rightarrow \pi^{\bar{+}} b^{\underset{-}{o}}$$

The mass and momentum of boson B is determined by the recoil spectrometers, while the decay spectrometer determines the angle and momentum of the pion. The mass of the b can then be calculated.

This experiment will determine which of the many possible π,b decay modes occur and their relative strengths. This knowledge of boson transition systematics will be of importance in testing current theories of boson classification and dynamics. In addition, it will be possible, in certain cases, to determine isotopic spin and G-parity. For those bosons decaying into a pion and neutral boson of known G-parity, the G-parity of the parent boson can be determined. Furthermore, if the neutral boson is an I-spin singlet, then the I-spin of the parent must be one. At present, there is no evidence to exclude the possibility of an I = 2 assignment for the presently known high mass mesons. Spin and parity will be determined for those bosons which decay into two spin-zero objects and are produced by spin-zero exchange.

From events in which both a pion and nucleon are detected, a two dimensional scatter plot of M_B vs M_b will be made. In this way, B resonances or peaks which lie close in mass to one another and cannot be resolved, will be identified.

For each boson tagged by a recoil spectrometer, the probability that the pion from the decay $B \rightarrow \pi + b$ will be detected is estimated to be about 50%. For this phase of the experiment the expected counting rate for charged boson produced with 10 μb total cross section and a t dependence of e^{-8t} is about 15,000/40 hrs for an incident beam of 10^6 pions per pulse. The rate for decay events (for unity branching ratio) is expected to be about 1/2 of this. The rates for neutral boson will be about a factor of ten lower.

A summary of the data rates expected from this experiment is shown in Table I. It is estimated that total time for testing, after the apparatus has been installed, would take about three months during which time about 150 hours of beam time would be necessary. 700 hours of data accumulation is requested. The data taking would be spread over four to six month interval.

Although the apparatus proposed has been designed with the detection of the two body decay modes as the prime objective, it is clear that due to the high degree of forward collimation of the decay products other decay mode information will be obtained.

3. Strange Boson Mass Spectrum

Since the incident beam will have a few percent K^- component, it will be desirable to tag events as π^- or K^- initiated. Data would then be obtained on the K^* mass spectrum and decay modes, similar to that of the non-strange meson but with poorer statistics.

TABLE I EXPECTED COUNTING RATES

Mass Range (GeV/c^2)	Average Mass Resolution (MeV/c^2)	Nucleon Angle (Deg)	Beam Energy (GeV)	Charged Boson events* per 10 μb	Decay events	Beam Intensity (per pulse)	Length of Run (hrs)
1.96 - 3.13	47	43^o - 67^o	24	15,400	7,700	10^5	40
3.10 - 3.56	38	25^o - 49^o	24	20,000		10^6	40
3.55 - 4.31	31	7^o - 31^o	24	30,000		10^6	40
2.95 - 4.28	66	43^o - 67^o	48	15,400	7,700	10^5	40
4.45 - 5.25	54	25^o - 49^o	48	20,000		10^5	40
5.18 - 6.0	43	7^o - 31^o	48	30,000		10^6	40
4.15 - 6.08	93	43^o - 67^o	96	15,400	$3,850^{xx}$	10^6	40
5.32 - 7.46	72	25^o - 49^o	96	20,000		10^6	40
7.32 - 8.60	62	7^o - 31^o	96	30,000		10^5	40

* Neutral boson events will be a factor of 10 less, strange boson events about a factor of 20 to 30 less.

xx At the high mass range the acceptance will be restricted to improve the resolution.

This experiment is similar to CERN-IHEP missing mass experiment being done at Serpukhov. The significant differences are:

1. This experiment will measure decay modes of neutral bosons as well as charged.

2. Data will be obtained for the strange mesons.

3. Data taking rate is about factor 5 higher due to the use of fast recovery spark chambers.

Although this experiment will be done several years after the Serpukhov experiment, it should be pointed out that the CERN data on the A_2 and R, S, T, mesons appeared in '65 - '66 and has yet to be confirmed.

II. Apparatus

A diagram of the apparatus is shown in Figure 1.

1. Recoil Spectrometers

The recoil proton spectrometer is now in operation at B.N.L. It consists of a set of spark chambers to determine the proton direction and scintillation counter arrays ΔE, E', and A. The protons of interest are non-relativistic and will stop in counter E'. Their energy then is proportional to the sum of the outputs of counter E' and ΔE. The ΔE counter is used to determine the particles rate of energy loss, dE/dx. This information together with that from E' is used to determine particle mass, since the product of dE/dx and E for a nonrelativistic particle is proportional to its mass. Time of flight information will also be recorded to further identify the proton.

This spectrometer is capable of measuring proton energies from 40 to 240 MeV with an energy resolution between $\pm$ 1% and $\pm$ 2%. At 240 MeV the loss of events due to nuclear interactions is about 25%.

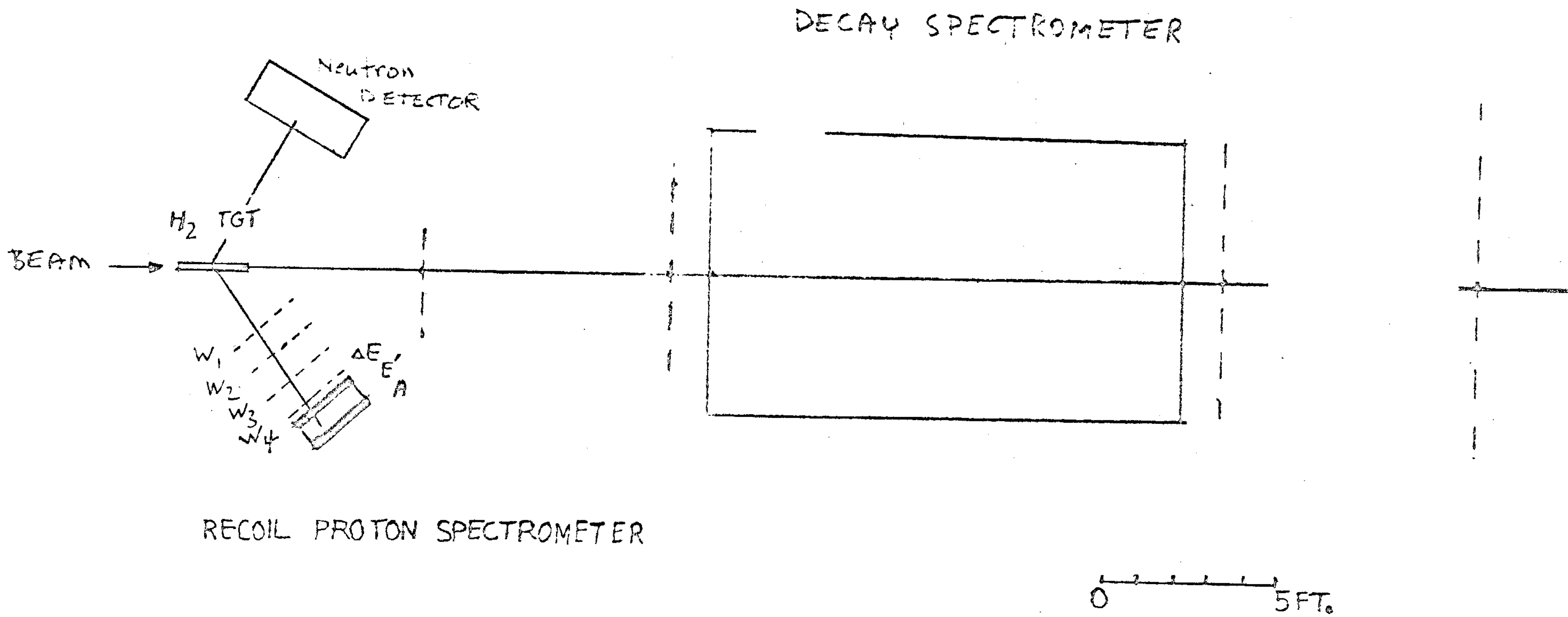


FIG. 1

EXPERIMENTAL ARRANGEMENT

The total aperture definedby the proton detector measures 20" in the vertical and 24" in the horizontal. This area is covered by five identical counter assemblies, each one covering a region 4" x 24". This subdivision results in a low probability that a proton will be accompanied by another particle in any given counter.

The counters are 5' from the target to permit time of flight rejection of fast particles. At this distance the total solid angle subtended by the system is about 120 msr.

The B^- mass resolution of the system has contributions from the uncertainties in beam energy, proton energy, and angle. The combined effect of these is a fractional boson mass uncertainty $\Delta m_b/m_b$ between $\pm$ 0.3% and $\pm$ 1.8%, depending on the angle and energy of the recoil proton and essentially independent of beam energy. (See Figure 2). In all cases the contribution to the resolution from the proton counter is less than or equal to that from the other two sources.

The neutron detector will operate in the Jacobian peak region where the mass resolution is dominated by the detector's angular resolution. Design studies of various possible neutron detectors which would have the necessary solid angle, resolution, and a smooth mass acceptance are presently under way. Both scintillation counter and spark chamber systems are being considered. It is planned to incorporate a neutron detector in the BNL experiment in early part of 1972 and thus a new detector need not be made.

2. <u>Decay Spectrometer</u>

The major component of the decay spectrometer is the magnet. The minimum magnetic volume necessary to achieve the goals of this experiment is 2m x 2m x 4m at 15 KG . With a pair of wire planes separated by 3.3m before and after magnet having a spatial resolution

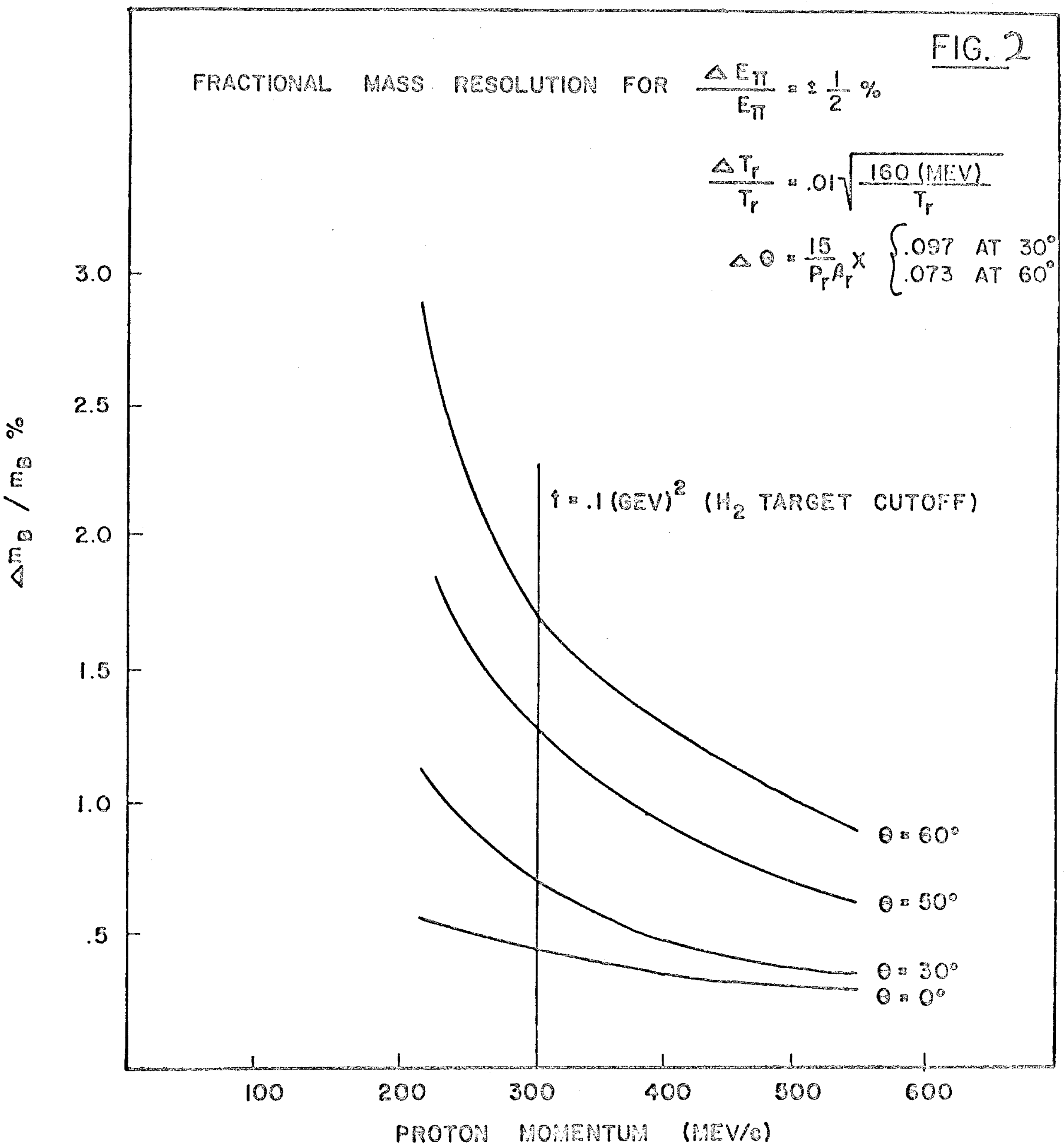

FRACTIONAL MASS RESOLUTION FOR $\frac{\Delta E_\pi}{E_\pi} = \pm \frac{1}{2}$ %
$\frac{\Delta T_r}{T_r} = .01\sqrt{\frac{160\ (MEV)}{T_r}}$
$\Delta\theta = \frac{15}{P_r \beta_r} \times \begin{cases} .097 & \text{AT } 30^\circ \\ .073 & \text{AT } 60^\circ \end{cases}$
$t = .1\ (GEV)^2$ (H_2 TARGET CUTOFF)
$\theta = 60^\circ$
$\theta = 50^\circ$
$\theta = 30^\circ$
$\theta = 0^\circ$
$\Delta m_B / m_B$ %
3.0
2.5
2.0
1.5
1.0
.5
100
200
300
400
500
600
PROTON MOMENTUM (MEV/c)

FIG. 2

of $\pm$ .3mm a $\Delta p/p$ of $\pm$ 1% can be obtained at 100 GeV/c^2.

The angular acceptance of the spectrometer is approximately $\pm 7^o$. This is sufficient to allow detection efficiencies of 50% or greater for two body decay modes having an isotropic angular distribution in the c.m. For such a distribution 50% of the decay pions have a lab angle between o and $\frac{m_B}{E_B}$ radians. For this experiment $\frac{m_B}{E_B} < \frac{1}{10}$.

The decay spectrometer should have sufficient resolution to separate the possible mass values of the decay boson. For the decay of the neutral boson, the decay boson must have I = 1 and their mass spectrum has a spacing of $\Delta m_b^2 = 1$ GeV/c^2. However, for the charged boson, the decay boson may be I = 0 and for this case the mass spacing is more like .33 GeV/c^2. We then take as acceptable a mass resolution of $\Delta m_b^2 < .33$ GeV/c^2.

The dominant contribution to this mass resolution is the momentum measurement of the pion produced in the decay. The effect of the uncertainty in this momentum on the mass resolution is given by:

$$\Delta m_b^2 \approx P_B \; P_\pi \; \left(\frac{m_B^2}{E_B^2} + \theta_{\pi B}^2 \right) \quad \frac{\delta P_\pi}{P_\pi}$$

where P_B, P_π are momentum of the produced boson and decay pion

m_B, m_b are the masses of the produced boson and decay boson

$\theta_{\pi B}$ is the angle between the decay pion and produced boson.

The estimated values for Δm_b^2 for mass ranges proposed are shown below. Note for the highest mass range it will be necessary to restrict $\theta_{\pi b}^2$ to be less than ${m_B}^2/{E_B}^2$ to achieve the desired resolution. This results in decreasing the detection efficiency for decay events by 50%.

TABLE II

E_B	m_B	m_b	$\frac{\delta P_\pi}{P_\pi}$	Δm_b^2
24	2.5	.1 - 2.3	$\pm$ .5%	.12
48	3.5	.5 - 3.2	$\pm$ .5%	.24
96	4.8	2.5 - 4.3	$\pm$ .7%	.32

3. Beam: A π^- beam at several momenta between 24 and 96 GeV/c with a flux between 10^6 and 10^7 pions per pulse in a $\Delta P/p_o$ band of $\pm$ 1%. Hodoscopes will be used to measure the incident momentum to $\pm$ .3% on an event by event basis.

4. Target 24" hydrogen target with a 2" diameter.

5. Computer The data from all counters and chambers are fed into a PDP-9 computer (provided by Northeastern), which records eventson magnetic tape for off-line analysis. The PDP-9 provides continous monitoring of the detection equipment. In order to monitor the physics result by means of complete event calculation it is highly desirable to have an on line data link to a larger computer. Presently we find the use of the PDP10 of the BNL-OLDF very satisfactory. The PDP10 program requires 40k of core and uses about 30% of the CPU time. We also would need about 200 hours of CDC6600 (or equivalent) time for off line analysis.

6. Software. We have the software for the PDP9 and the on line data analysis and will certainly have the off line analysis programs complete within a year.

7. Cerenkov Counters. Beam cerenkov counters will be necessary to separate the K initiated events from the π initiated events.

8. Electronics.

The electronics required for this experiment are special electronics for the proton and neutron detector, fast recovery spark chamber pulsing circuits, commerical fast electronics for the triggering logic which has a computer controlled selective trigger, and computer interfaces.

Of the above equipment NAL would provide the target, beam cerenkov counters, magnet and mechanical supports for the decay spectrometer planes, a suitable computer for on line data analysis, and commerical electronics for the trigger logic. The experiment would require 150 logic models, 20 power supplies and 25 scalers.

We plan to provide the proton detector, and neutron detector with their specialized electronics, beam hodoscopes, PDP9 computer and interface, and spark chambers for the decay spectrometer. Except for the neutron detector and decay spectrometer chambers, this equipment is operating at BNL now. The neutron detector will be built for use at BNL, so the spectrometer chambers would represent the only additional large piece of equipment we would have to provide.

We plan to finish the BNL experiment towards the end of 1972. At that time the equipment plus all the necessary software should be available for use at NAL.

November 3, 1974.

To: JIM SANFORD AND MEMBERS OF PAC.

From: EB VON GOELER, SPOKESMAN, EXP. 51A.

Subject: SUPPLEMENTAL MATERIAL SUBMITTED IN SUPPORT OF A REQUEST FOR ADDITIONAL BEAMTIME FOR EXPERIMENT 51A.

Table of Contents.

Section I. Summary of Requested Running Time.

Section II. Apparatus.

Section III. Physics.

(1) Particle Searches.

(2) Single Particle Inclusive Study.

Section IV. Current Status of E-51A and Results.

(a) H_2 Target and Negative Beam.

(b) H_2 Target and Positive Beam.

(c) D_2 Target and Positive Beam.

The deuteron recoil events are collected simultaneously with the recoil proton data. In our test run at 100 Gev we found the deuteron yield to be about 6% of the proton yield.

The run plan we would follow is given in Table I. The time necessary to collect the deuterium data is 220 hrs. and 100 hrs. for the hydrogen data. Considering the time necessary for set up and tuning, calibration, target out runs, and beam down time we realistically expect that it would take 4 weeks with a deuterium target and two weeks with hydrogen to achieve these goals. We assign the highest priority to the 200^+ Gev positive runs on deuterium and hydrogen as these are necessary to extend the search for high mass neutral bosons to the highest mass value. The 200^- and 100^- Gev have the next priority. They are necessary to study the exotic mass spectrum. The lowest priority is given to the 40 Gev data. These are desired so that we span a large range in s in order to pin down any systematic scaling behavior of $\frac{d^2\sigma}{dt\, d(m^2/s)}$.

Table I Run Plan

A. Deuterium Target

Beam Particle,	Momentum (GeV)	Time (hrs)	Expected recoil proton yield / mass sq. bin*
π^+	200	80	>4 K
p	200	24	7200
π^-	200	24	7200
π^-	100	24	7000
π^+	40	24	7700
p^+	40	24	7700
π^-	40	24	7700

B. Hydrogen Target

π^+	200	40	1700
p^+	200	90	3800
π^+	40	35	1100
p^+	40	35	1100

* Bin defined as δM^2, where δM^2 is the FWHM resolution, given by $\delta M^2/s = 5\times10^{-2}$ for D_2 ; $\delta M^2/s = 5\times10^{-3}$ for H_2

Section II. Apparatus

Experiment 51A was approved as a missing mass study of reactions

$$\text{hadron} + p \rightarrow p + X ,$$

detecting the slow recoiling proton. Fig. 1 is a schematic of the apparatus as set up in the Meson laboratory. Scintillation and Cerenkov counters and hodoscopes define the beam coming from the left. Protons and deuterons originating from interactions in the target are detected in a moveable spectrometer. Spark chambers (SC) and a proportional chamber (PCS) measure the trajectory of the recoil particles. The particle mass and kinetic energy is measured by an array of scintillators using a combination of energy and $\frac{dE}{dX}$ and time of flight techniques. A proportional chamber (PCF) 30 feet downstream of the target detects elastically scattered particles, mostly for calibration purposes, but in principle capable of separating elastic and quasielastic events. The outputs of two scintillators (M) located approximately 12 feet downstream of the target are pulse height analyzed to give a crude measurement of the number of charged particles produced in the reaction. Data taking, under the control of a PDP9 computer, proceeds at high rates (up to 100 events/sec.).

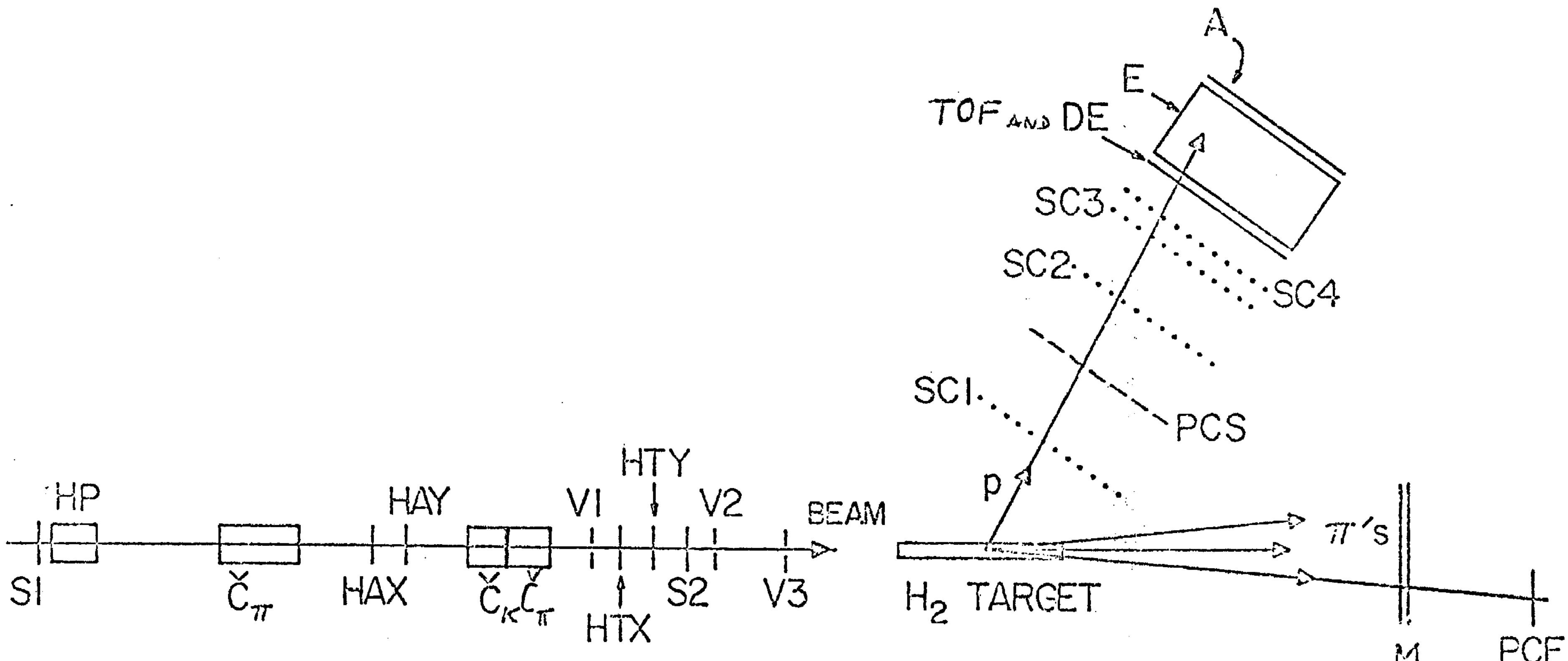


Fig. 1 Exp. 51A DETECTOR LAYOUT

Section III. Physics.

Missing mass spectra can be studied with an eye on two entirely different processes, both of which are of high current interest, and both of which have motivated this experiment.

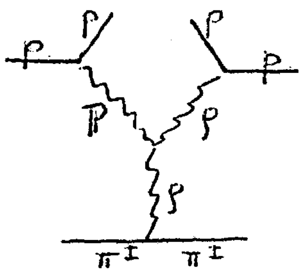
1) Particle Searches. Since the technique allows a rapid survey of a large mass interval it is eminently suited to search for possible high mass objects produced with cross sections of the order a few microbarns or more. A "gluon" of mass 10 GeV, for example, might be visible as a bump over an otherwise smoothly varying mass spectrum. The apparatus resolution for such an object is less than a pion mass.

During the August and October runs we completed a particle search for negative bosons in the mass range $-100 \leqslant M^2 \leqslant +170$ GeV^2. Use of a deuterium target would extend this search in three essential ways: (a) reaction $\pi^+ n = pX^o$ constitutes a search for neutral gluons, (b) reaction $\pi^{\pm} d = dX^{\pm}$ extends the M^2 range by a factor 1.4, (c) the exotic spectrum $\pi^- n = pX^{--}$ could be explored.

2) Single Particle Inclusive Study. The experiment is a measurement of the invariant cross section $s \frac{d^2\sigma}{dt\,dM^2} = f(s, M^2, t)$ over a wide range of M^2 and s. The region of $M^2/s = 1-x$ covered is approximately $M^2/s \leqslant .35$, with mass resolution $M^2/s = 5 \times 10^{-3}$ fwhm, independent of M^2. The t range is $.1 < t < .4$ GeV^2. The data therefore cover the quasielastic region as well as the fragmentation region permitting studies of the respective s dependences.

The functional dependence of f on s, M^2, and t has been predicted by detailed models inspired by Regge theory. In the triple Regge model it is important to measure the triple Reggion couplings and to relate them to other data. The large range of s and M^2 in the measurements allows a separation of the individual terms contributing to the cross section. Such studies exist for proton initiated reactions and will be provided in the present experiment for both the $\pi^- p$ and the $\pi^+ p$ cross section.

Comparisons of these cross sections will be very interesting. Predictions are, of course, model dependent. For example, in the triple Regge model the quantity $f_- - f_+$ isolates the single term indicated in the diagram. It is an interference term usually neglected for the sake of simplicity. Its measurement will tell whether its omission is justified.



Use of a deuterium target will allow studies of reactions $\pi^{\pm} n = pX^{0-}$. In order to do this, the measured cross section for $\pi p = pX$ has to be subtracted from the measurement $\pi d = pX$ taking the Fermi momentum of the target nucleon into account. The reward, for positive beam, is a cross section free of quasielastic events. For negative beam, it is a measurement of exotic channels.

In addition, these data yield information on reactions $\pi^{\pm} d = dX^{\pm}$. Here diffractive production is strongly emphasized because $I \neq 0$ exchange is suppressed, there is no target excitation. The counting rate is fairly small because of the deuteron form factor. We find the yield to be about 6% of the proton yield.

Section IV. Current Status and Results

We now have data for positive and negative beams on a hydrogen target and a small amount of test data for positive beam on a deuterium target. These data are summarized in Tables II and III.

A. Hydrogen target and negative beam

Our data taking program for this category has been completed. The high mass resonance search sensitivity is a few microbarns, depending on the mass and width of the resonance. This corresponds to about 3% statistics per mass^2 bin, which was chosen to equal the experimental resolution. Figure 2 is an unormalized cross section obtained from a small sample of the $\pi^- + p \rightarrow p + X^-$ data at 200 Gev.

B. Hydrogen target and positive beam

For a 100 Gev positive beam on hydrogen, data taking was completed during October. The natural mix of π^+ and p in the beam was used, resulting in 40% pion and 60% proton initiated events. Figures 3 and 4 are preliminary unnormalized cross sections takon from a 15% sample of the data. The proton data overlap the region in which results are available from the Internal Target Area. As is indicated on the histogram, the region of x covered by exp. 51A extends far beyond that of the ITA experiment.

A small amount of data was taken with a 200 Gev positive beam. Since the natural mix of pions and protons was used, the data at this energy are about 97% proton initiated. A brief test proved that including one of the three beam Cerenkov counters in

Table II Data obtained off Hydrogen by Exp 51A during August and October Runs

Reaction	Energy (GeV)	|t| range (GeV^2)	M^2 range (GeV^2)	Resolution δM^2 (GeV^2) FWHM	# events obtained	# events per δM^2
$\pi^- p \to pX^{--}$	240	0.1 – 0.4	+70 to +170	2.4	31 K	750
	200	"	−100 to +140	2.0	190 K	1600
	100	"	−50 to +60	1.0	110 K	1000
	40	"	−20 to +25	0.4	67 K	600
$\pi^+ p \to pX^+$	200	0.1 – 0.4	−70 to +120	2.0	none	—
	100	"	−50 to +60	1.0	60 K	550
	40	"	−20 to +25	0.4	none	—
$pp \to pX^+$	200	0.1 – 0.4	−70 to +120	2.0	28 K	300
	100	"	−50 to +60	1.0	82 K	750
	40	"	−20 to +25	.4	none	—

Table III Data obtained off Deuterium by Exp 51A during October test run.

Reaction	Energy (GeV)	$\|t\|$ range (GeV^2)	M^2 range (GeV^2)	Resolution δM^2 (GeV^2) FWHM	# events obtained	# events / δM^2 bin
$\pi^+ d \to p X$	200	.05 to .4	−100 to 140	20	3K	250
	100	"	−50 to 60	10	65K	6000
$pd \to pX$	200	.05 to .4	−100 to 140	20	34K	2800
	100	"	−50 to 60	10	82K	7400
$pd \to \underline{d} X$	200	~.1 to 1.	−100 to 200	2	2.5K	17
	100	"	−50 to 85	1	4.8K	36
$\pi d \to \underline{d} X$	200	~.1 to 1.	−100 to 200	2	200	~1
	100	"	−50. to 85.	1	4.8K	36

FIGURE 2.

MASS PLØT ØF 37.5+45+53+60+75+82.5 DEGREES DATA. T=0.2 TØ 0.3 GeV^2

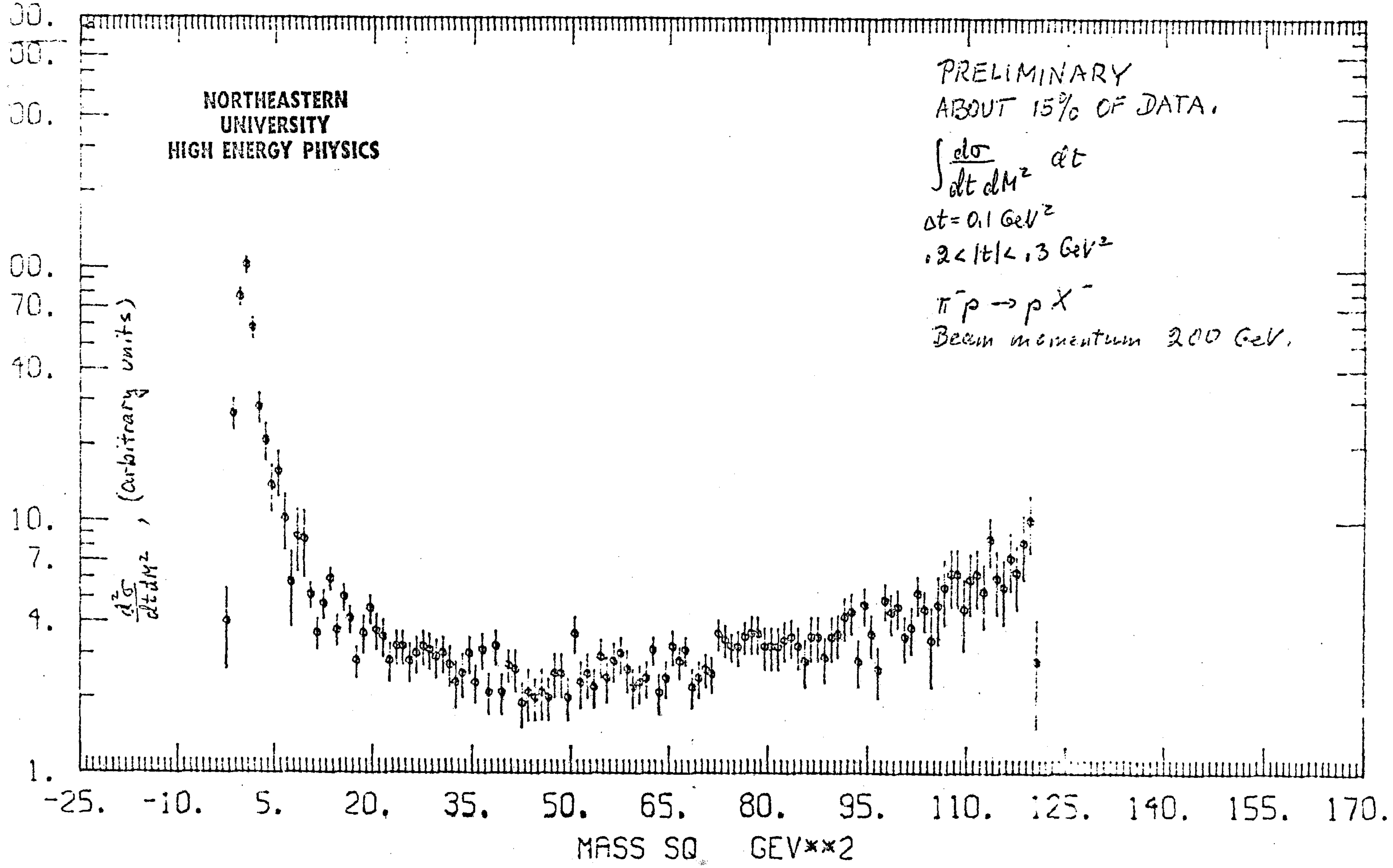
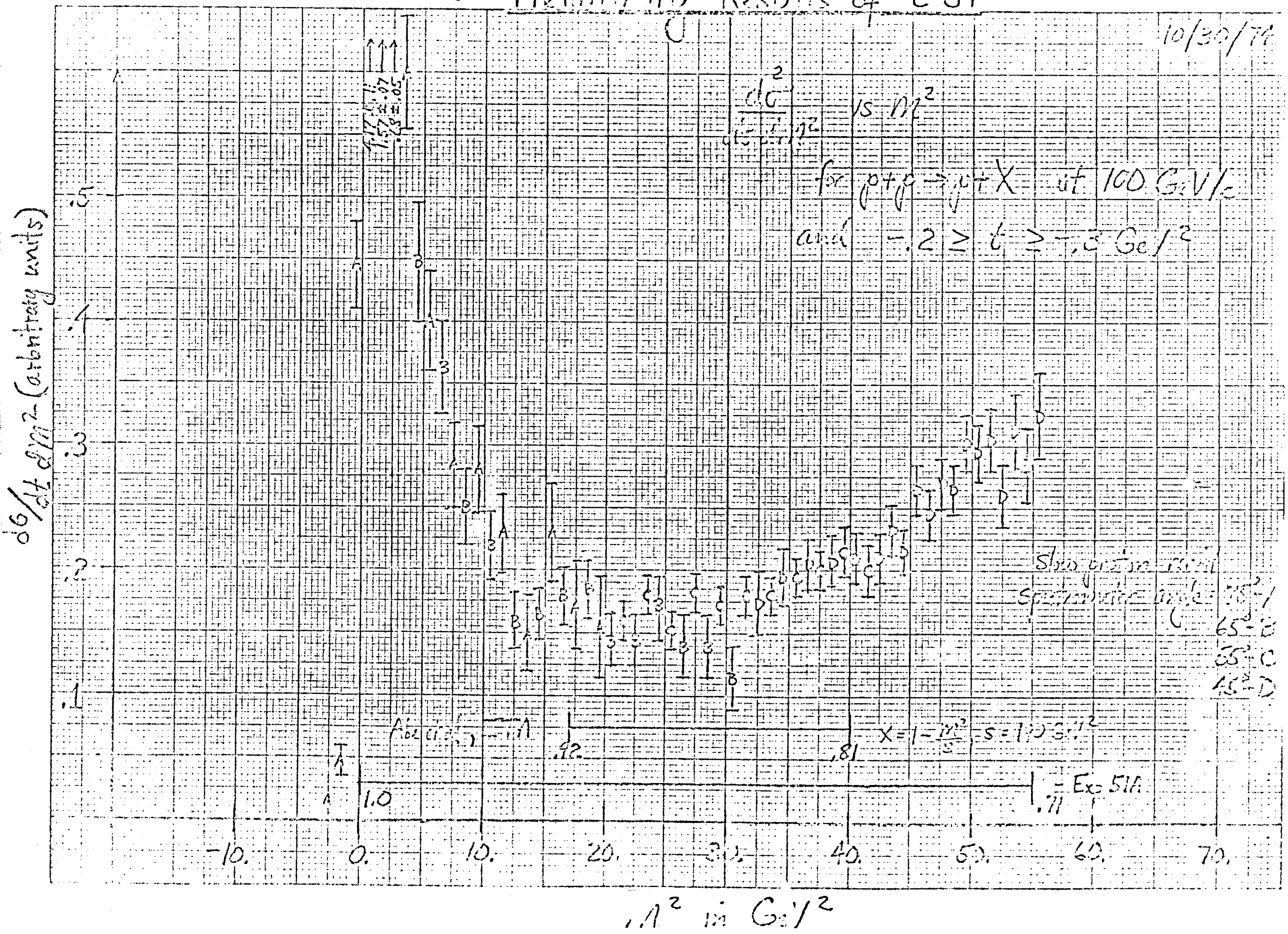
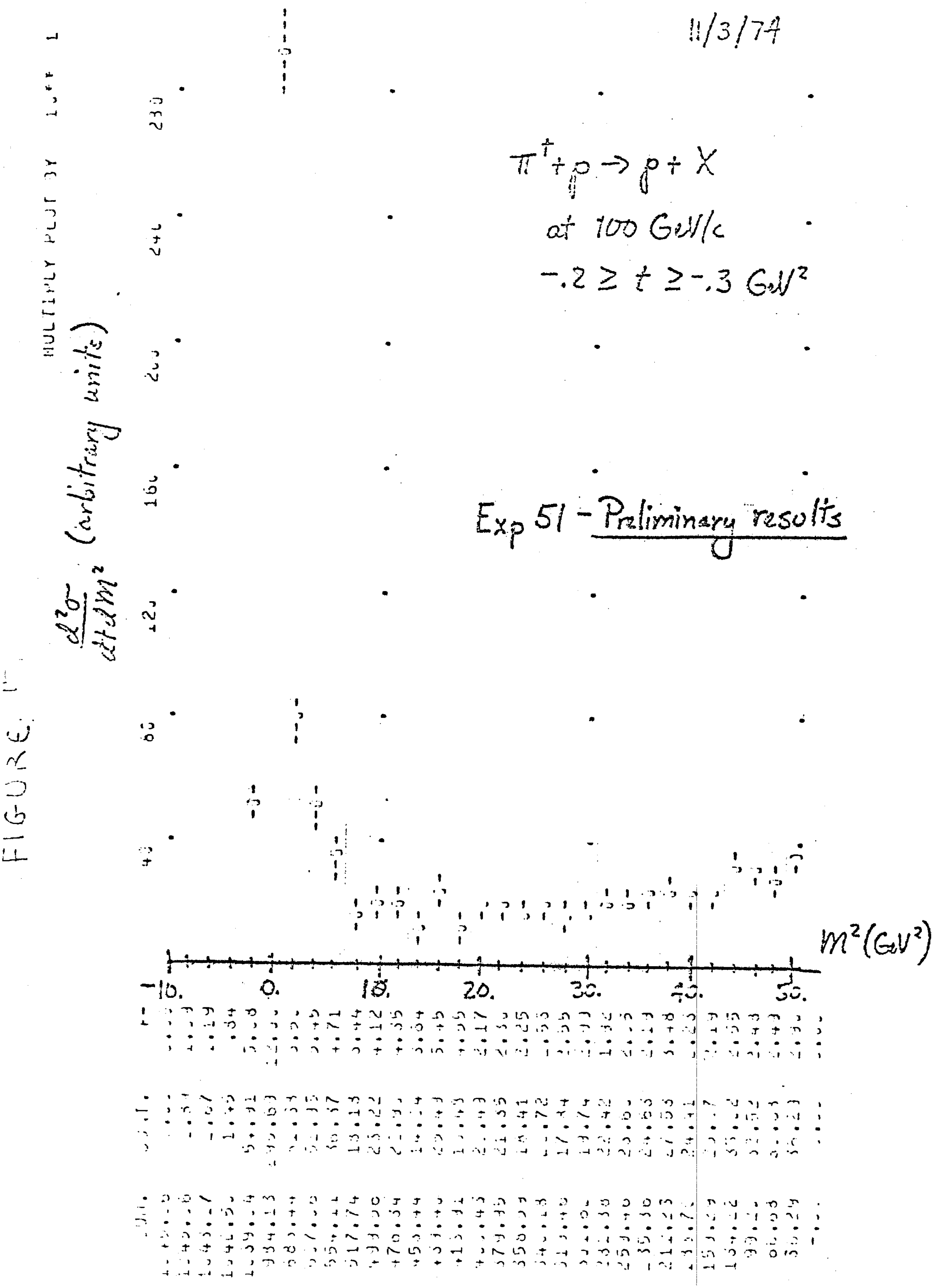


FIGURE 3. Preliminary Results of E51





11/3/74
$\pi^+ + p \to p + X$
at 100 GeV/c
$-.2 \geq t \geq -.3$ GeV^2
Exp 51 - Preliminary results
M^2 (GeV^2)
$\frac{d^2\sigma}{dt\,dM^2}$ (arbitrary units)
FIGURE
MULTIPLY PLOT BY
-10.
0.
10.
20.
30.
40.
50.

the trigger logic enhances the fraction of pion initiated events to better than 80% without deteriation of the beam pion identification. In this mode, our trigger rate was about 20 per pulse. As Table III indicates, the statistical significance of our 200 Gev positive data falls far short of that at the 200 Gev negative data, so the extra beam time is very important.

C. Deuterium target and positive beam

With a deuterium target and a positive beam we measure the following six reactions,

$$\left\{\begin{array}{l} \pi^+ + n(p_s) \rightarrow p(p_s) + X^0 \\ \pi^+ + p(n_s) \rightarrow p(n_s) + X^+ \end{array}\right\}$$

$$\left\{\begin{array}{l} p + p(n_s) \rightarrow p(p_s) + X^0 \\ p + p(n_s) \rightarrow p(n_s) + X^+ \end{array}\right\}$$

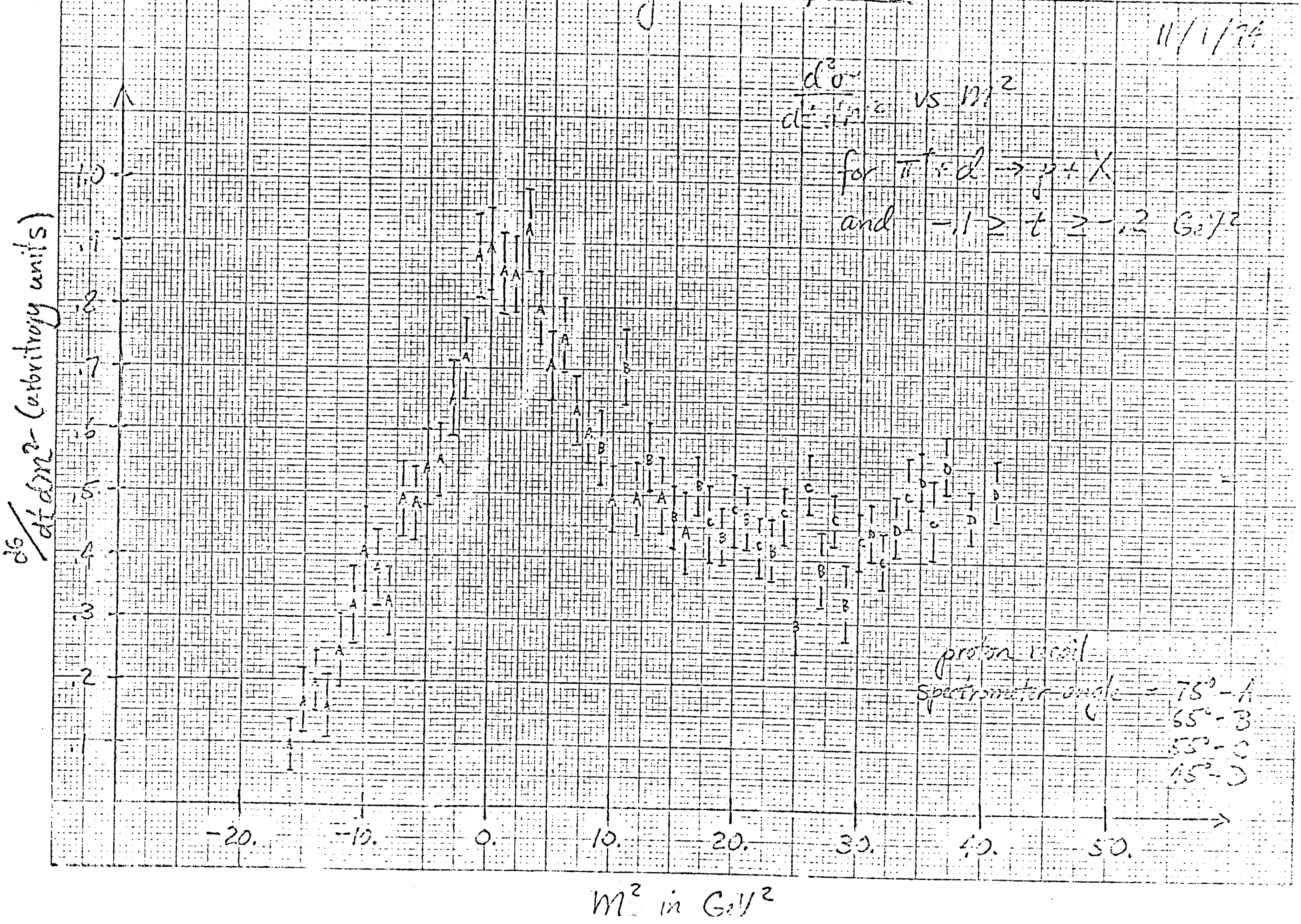
$$\pi^+ + D \rightarrow D + X^+$$

$$p + D \rightarrow D + X^+$$

where the subscript " s " refers to the spectator nucleon, and the bracketed reactions are probably experimentally indistinguishable (our multiplicity counters may help distinguish between neutron and proton spectators).

A small amount of data was obtained in brief test runs at 100 and 200 Gev. Figure 5 is a preliminary unnormalized cross section taken from a 15% sample of the 100 Gev pion initiated data. The elastic scattering peak, which dominates the data taken with the hydrogen target, has been broadened by the Fermi momentum of the nucleons in deuterium. The magnitude of this effect is as predicted by Monte Carlo calculations. In order to extract the

FIGURE 5. Preliminary Results of E51



neutral missing mass spectra, we will subtract the hydrogen target data 'smeared" to account for the Fermi momentum. Since we separate elastic from inelastic events by detecting the scattered fast particle, we will be able to test the subtraction procedure by comparing elastic cross sections obtained from deuterium and hydrogen.

The test runs also demonstrated the deuterium detection capability of the E51a apparatus. Figure 6 is a scatter plot against two variables, each of which is a function of the mass of the particle detected by the spectrometer. The deuterons are distinctly separated from the protons. Figure 7 is an uncorrected (missing mass)^2 spectrum obtained at a spectrometer angle of 85°. All beam particles were used to increase the statistics in the events in this plot. The events in this plot were reduced from a 2 hour, 80000 trigger run. The elastic peak, made asymmetric by diffractive dissociation, is clearly visible. During the deuterium test run the trigger logic was altered so that the recoil particle was not required to penetrate the dE/dx counter but could stop in it. This increased the elastic deuteron scattering yield by a factor of two; separation from protons of these events was accomplished by time of flight measurement.

The prospect of measuring missing mass spectra off deuterium seems especially appealing since the spectra have no contribution from decay of excited states of the target particle.

FIGURE 6.

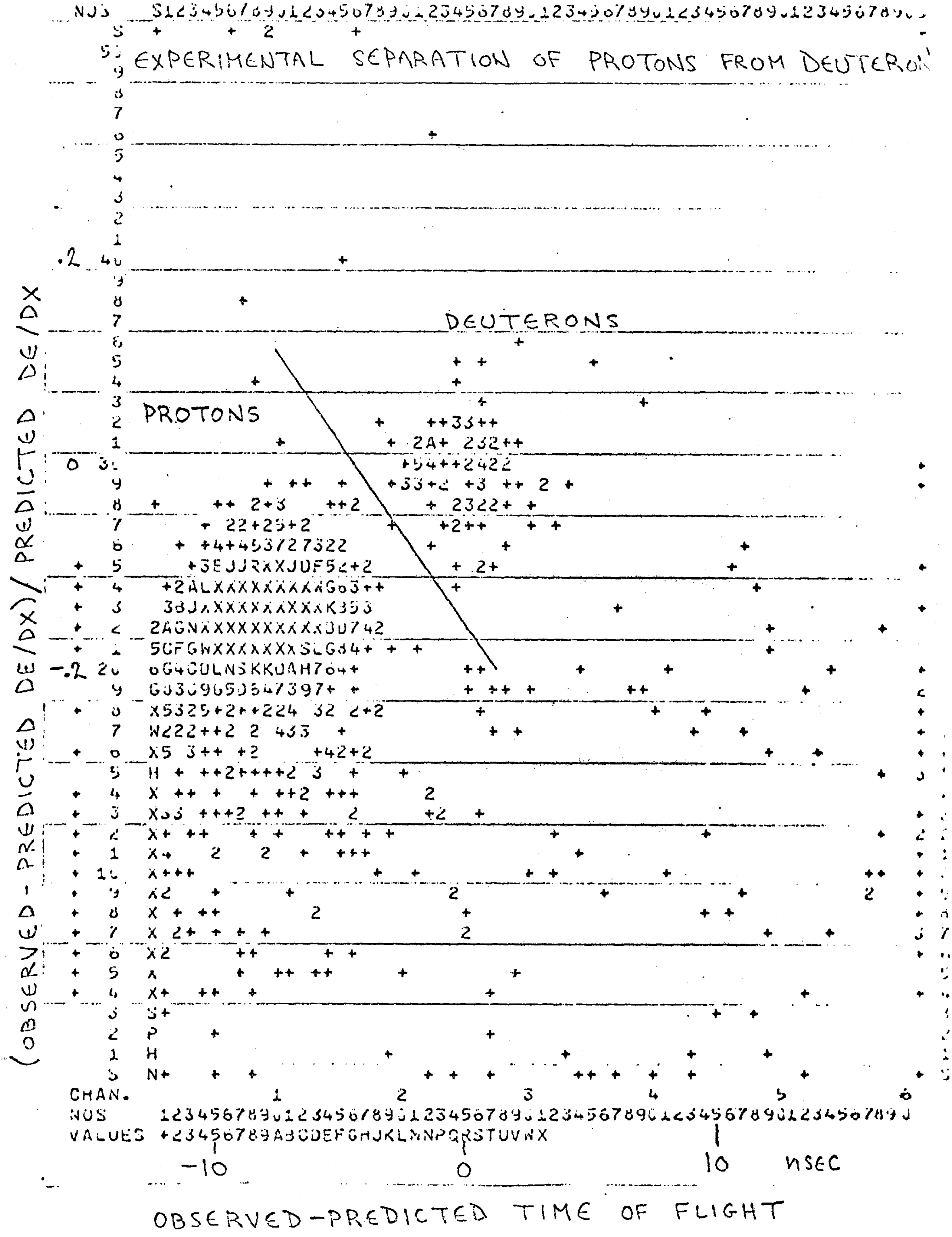
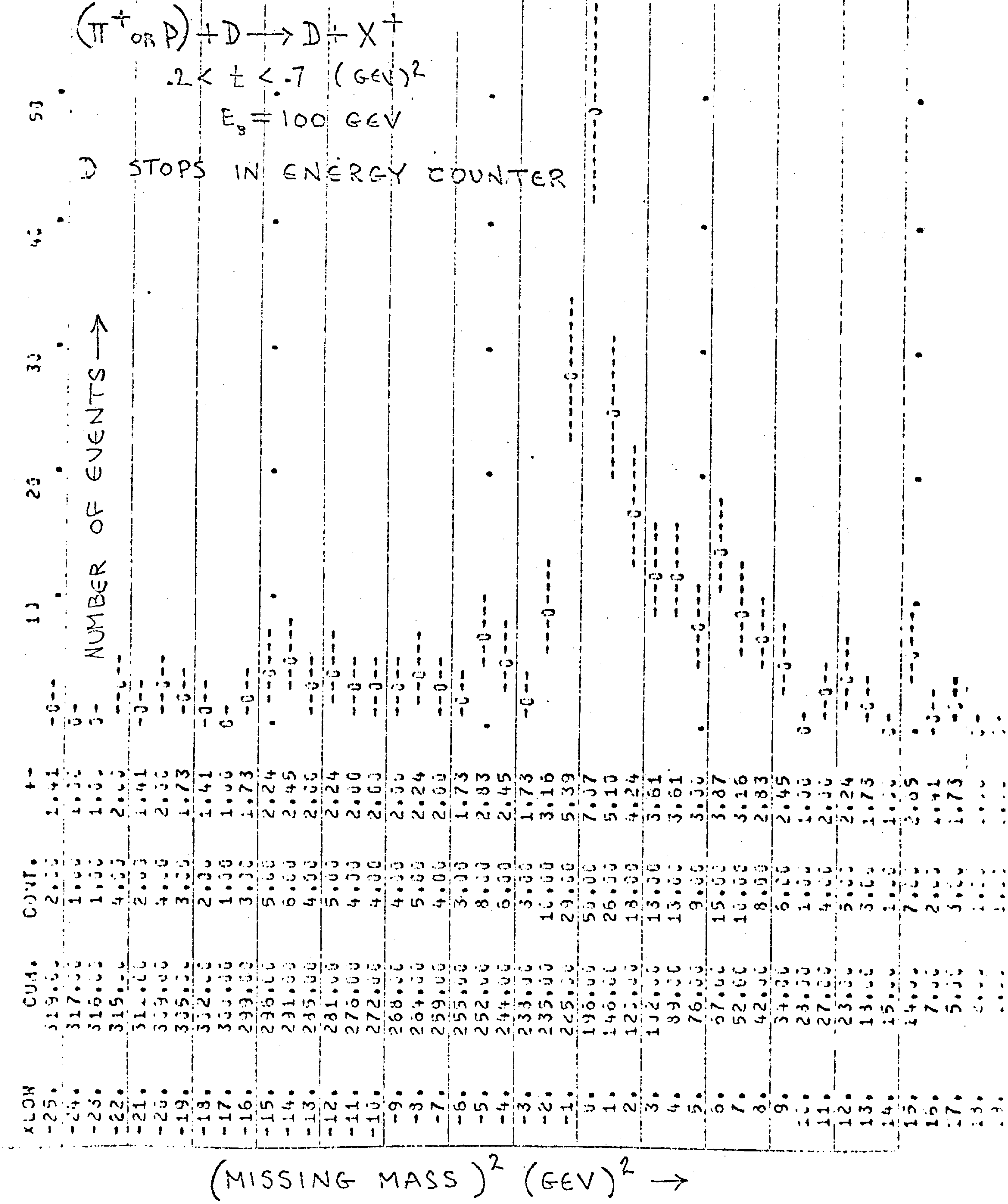

EXPERIMENTAL SEPARATION OF PROTONS FROM DEUTERONS
DEUTERONS
PROTONS
(OBSERVED - PREDICTED DE/DX)/ PREDICTED DE/DX
.2
0
-.2
CHAN.
NOS
VALUES +23456789ABCDEFGHJKLMNPQRSTUVWX
-10
0
10
NSEC
OBSERVED-PREDICTED TIME OF FLIGHT

FIGURE 1.


$(\pi^{+}$ OR $P) + D \rightarrow D + X^{+}$
$.2 < t < .7$ (GEV)^2
$E_{\delta} = 100$ GEV
D STOPS IN ENERGY COUNTER
NUMBER OF EVENTS →
(MISSING MASS)^2 (GEV)^2 →

11-15-74
8:10 a.m. (Recd. via telephone)

Telegram from Brookline, Mass.
for R. R. Wilson

Request immediate scheduling of Experiment 51 effective mass measurements using CCM magnet spectrometer to discover existence of charmed particles produced in hadron-nucleon collision. Will look for charmed particles decaying into K's and pi's. Charmed particles to be identified by the appearance of narrow peak in the effective mass spectra. For theory details, please see Fermilab publication 74-86-THY for effective mass resolution and acceptance. See Experiment 51 original proposal presented to PAC Nov. 3, 1971. Happy to explain additional details. Can come to FNAL with about four hours advance notice. Wire or call response.

D. Garelick
Northeastern University

NORTHEASTERN UNIVERSITY

BOSTON, MASSACHUSETTS 02115

DEPARTMENT OF PHYSICS

November 10, 1971

Dr. R. R. Wilson and Members of the PAC
National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510

Gentlemen:

As we have indicated in our letter of October 12 to Dr. Wilson, and in our discussions at the PAC meeting at NAL on November 3, we are prepared to carry out the measurements defined in proposal #51.

As discussed in detail in the enclosed material, we can carry out proposal #51 using a "converted" μ beam and the Chicago cyclotron magnet. After careful study, we are confident that the conversion of the μ beam to a high quality hadron beam will not require a large effort. More specifically, we have designed two hadron beams, both of which use only existing μ beam magnets and enclosures. One beam is a π^- beam that is compatible with the NAL narrow band ν beam and the other beam is a secondary proton beam which is compatible with both the narrow band and broad band ν beams. Both beams require only $\sim 10^{12}$ protons from the accelerator. We can carry out most of the experiment (debugging, testing, and proton data) in a mode that is compatible with both the broad and narrow band ν programs.

We have also investigated the compatibility of our proposed detector system with that of the NAL μp Collaboration and found that the incompatibilities between the two experiments are minimal. In fact, we are most willing to make use of many of the detectors that will be used in the μp experiment, especially the large spark chambers.

We hope that the detailed information that we have previously supplied (NAL proposal #51 and revisions 9/22/70, and NAL proposal #140 and additional details, letter to J. Sanford 8/3/71) along with the enclosed information have provided sufficient descriptions of the experiment.

One of us (EvG), a senior member of our research group, has arrived at NAL to spend one year, full time, at NAL in order to provide a liason between NAL and our group. We hope that this full time presence at NAL plus the part time presence of other senior people in our group will allow our experiment to proceed at the maximum rate possible.

In summary, we believe that our physics is of great interest, that we have previously demonstrated our capability to carry out such an experiment, and that our requests for accelerator time, intensity and equipment are reasonable. We hope an approval of the experiment is possible in the very near future.

If we can provide any further information or be of help in any way, kindly let us know.

Eberhard von Goeler

David Garelick

Marvin Gettner

Roy Weinstein

cc: J. Sanford

Northeastern University
High Energy Physics Group
11/5/71

Summary of Physics and Logistics

(Presented to the NAL-PAC 11/3/71)

(Experiment #51, 11/5/71 revision. Information, supplementary to information already provided, in association with proposals #51 and #140.)

Primary Physics Goals

The main goal of our measurements is to search for and measure the quantum numbers of high mass ($2 \leq M \leq 10$ GeV) hadron states using all techniques available in the proposed apparatus. At a minimum this means using single and double missing mass as well as effective mass techniques. The study of the production dynamics of known resonances will not be a primary goal in the experiment. However, the final data will be examined for dynamical effects and will provide useful information about inclusive reactions, etc. at high energies.

More specifically, we propose to accumulate approximately 2×10^7 events with excellent single missing mass, double missing mass, and effective mass resolutions. These studies are a continuation, to higher energies and more complete measurements of the events, of an experiment we recently completed at the Brookhaven AGS (in collaboration with SUNY at Stony Brook) which examined the $0.1 \leq M \leq 2.7$ GeV region.

Reactions to be Studied*

(a) $\pi^- p \to \pi^{-*} \underline{p}$

(b) $\pi^- p \to \pi^{-*} \underline{p}$

- $\pi^{-*} \to \underline{\underline{\pi}}^- \, b^o$ (b1)
- $\pi^{-*} \to \rho^o \, b^-$, $\rho^o \to \underline{\underline{\pi}}^- \underline{\underline{\pi}}^+$ (b2)
- $\pi^{-*} \to A_2^- \, b^o$, $A_2^- \to \underline{\underline{\pi}}^- \underline{\underline{\pi}}^- \underline{\underline{\pi}}^+$ (b3)
- $\to$ etc. (b4)

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*Single underlines indicate particles detected in the proton spectrometer; double underlines indicate particles detected in forward spectrometer; triple underlines indicate particles detected in a cylindrical range detector.

(c) $\pi^- p \to \pi^{-*}$ + (anything) (c1)
$\hookrightarrow$ all charged

$\to b^{o*}$ + (anything) (c2)
$\hookrightarrow$ all charged

(d) $\pi^+ d(n,p) \to (b^o)^* \; \underline{p} \; p_s$

p_s is spectator proton which does not escape H_2 tgt.

$\hookrightarrow$ all charged (d1)

(e) π^- nucleus $\to (\pi^-)^*$ + (anything)
$\hookrightarrow$ all charged (e1)

$\to (\pi^-)^* \; \underline{\underline{p}} \; \underline{\underline{p}}$ + (anything)
$\hookrightarrow$ all charged (e2)

The analogus reactions, (a') $\to$ (e'), using incident protons will also be studied. However, the analysis of the proton events might be more formidable since no $\pi^\pm$, $K^\pm$, $p^\pm$ separation will be made of the particles detected in the forward spectrometer.

Reactions (a) and (b1) represent the single and double missing mass measurements which are extensions to higher energies of our BNL measurements. The detected proton provides the "high mass" trigger. Since the forward spectrometer (unlike the forward spectrometer used at BNL) has a large acceptance, effective mass spectroscopy will also be carried out.

Reaction (d) studies neutral high mass objects which decay into charged particles. The detected proton provides the high mass trigger and the requirement that the number of charged particles leaving the hydrogen be an odd number insures that the H^* (H = hadron) production took place from the target neutron via $Hn \to H^* p$.

Reactions (e1) and (e2) will be studied to examine H^*'s which require two single nucleon collisions in order to be made with appreciable cross sections, for example

$$\pi^- \mathrm{Nuc}(p,p,\ldots) \to (A_2^- \; \mathrm{Nuc}(,p,\ldots)) \to (A_2^{-*} \; \mathrm{Nuc}(,,\ldots))$$
$\hookrightarrow$ all charged

The trigger, in this case, will be two slow protons coming out of a heavy nuclei target, or a broader trigger to detect stars.

The major protion of the experiment will study reactions (a), (b), (a'), and (b') and less than one-third of the data time will be devoted to the less established methods (c,c'), (d,d') and (e,e').

Apparatus

We proposed to study reactions (a) → (d) and (a') → (d') with an apparatus similar to that indicated in Figs. 1 and 2 using a hadron beam of 10^5 particles per pulse (1 sec spill). At this rate, even those spark chambers directly in the incident beam should have a tolerable number of background tracks, even with no dead spots for the incident beam. (The beam is discussed in detail, below, in the Beam Logistics section).

The proton spectrometer shown in Fig. 1, except for the detectors immediately adjacent to the H_2 target (cylindrical proportional chamber and decay hodoscopes) is the one used in our BNL-AGS experiment. The forward spectrometer uses spark chambers and scintillation hodoscopes as detectors.

Hodoscopes and spark chambers almost identical in active areas and spatial resolution to these needed for our experiment are currently being constructed by the Muon-Proton Inelastic Scattering Experiment Collaboration (Chicago, Harvard, Oxford Collaboration). We are presently exploring the possibility of using some of the equipment constructed by the μp Collaboration. However, if this is not practical, we would ourselves construct the detectors shown in Fig. 2.

Run Plan, Event Rates, Sensitivities to Resonances, and Mass Resolutions

The run plan, event rates and mass resolutions are given in Table 1. In arriving at the data rates, we have assumed a conservative system dead time, for both the proton and forward spectrometer being pulsed, of 50 m sec/event. The calculated coincidence trigger rate, at 10^5 in the incident beam, is $\sim$ 25 m sec/trigger and the proton spectrometer will be pulsed at this rate. The effective mass trigger rate, reactions (c), (c'), (e) and (e') should be very large, approximately 0.2 m sec/trigger. Thus, during the effective mass trigger runs, specific topologies will be selected in the trigger, based on the number of charged particles observed by the forward spectrometer, so that the more interesting rare topologies can be studied in detail.

The experiment's sensitivity to resonances is approximately 10^3 events/μ barn for each 100 hours of data collection time. The actual signal to noise ratios for resonance production is difficult to estimate but is expected to be for "narrow" resonances (i.e. resonances where Γ experimental $\geq \Gamma$ physical), for single missing mass data with no data cuts, signal: noise $\simeq$ 1:20 for σ (resonance) $\simeq$ 5 μ barns, and for double missing mass, specific topologies (for example $p\pi^-\pi^o$ final states, i.e. resonances decaying into $\pi^-\pi^o$) signal:noise $\sim$ 2:1 for σ(resonance) $\sim$ 5 μ barns. These estimates are based on a simple extrapolation of our BNL results to higher energies.

Beam Logistics and Beam Scheduling

The beams, parameters of which are indicated in Table I, have been designed to be compatible with the beams used in both the narrow band and broad band ν experiments. All apparatus debugging, calibrations, and all proton data can be recorded when the broad band ν experiments are running. This will require the extraction of $\sim$ 6 x 10^{11} (or $\sim$ 2% of the NAL design intensity) protons onto the ν experiment target, for $\sim$ 1 sec, after the short spill ν pulse has taken place. Only the π data will require the narrow band ν front end (maximum of 600 hours of data taking), and can be carried out in less than three calendar months.

We can set up the experiment in one month, debug the apparatus and record the proton data in the next three calendar months, while either the narrow band or broad band experiments are running, and then record the π data, during a narrow band ν experiment, in the final three calendar months of the experiment. (We have assumed that the narrow band ν experiments will operate with the first stage of the beam set to 100 GeV, P(primary) $\simeq$ 200 GeV, for at least 400 hours and set to 200 GeV, P(primary) $\sim$ 400 GeV, for at least 200 hours during our π^- runs.)

Availability of Equipment and Manpower to Carry Out Experiment

Assuming the large spark chamber and hodoscopes can be borrowed from the μp Collaboration, we can prepare the remaining equipment and computer software by January 1973 and complete the experiment by [redacted] August 1973, providing the necessary beam time specified in Table I is available during this time.

If this experiment is scheduled and begun on or before January 1974 it will be the dominant research effort, and only major experiment, in which our group is involved. We expect that approximately 10 Northeastern University physicists will make this experiment their sole research effort. Three of these physicists are expected to be full time research associates with no teaching responsibilities. If NAL, at this time, approves and schedules this experiment to run prior to January 1974, we request that Proposal #140 be no longer considered active.

Other Requirements etc.

It is hoped that other requests and requirements (for example computer time and electronics requests) previously conveyed to NAL concerning Proposals #51 and #140, along with the proposals themselves, have provided enough details so that the PAC and NAL staff can make a decision on this experiment at this time.

TABLE I

Run Plan, Event Rates, and Mass Resolutions

Symbol definitions; typical reactions i) $\pi^- p \rightarrow \pi^{-*} \underline{p}$, $\pi^{-*} \rightarrow \underline{\underline{\pi}}^- b^o$ ii) $pp \rightarrow (p)^* \underline{p}$, $(p)^* \rightarrow \underline{\underline{p}}\ b^o$

	Beam Particle	Beam Momentum (GeV)	Reactions Studied	Secondary Beam Configuration*
1)	π^-	100	(a), (b)	NB ν
2)	π^-	200	(a), (b)	NB ν
3)	π^-	100	(c),(d),(e)	NB ν
4)	p	100	(a'),(b')	BBν or NBν
5)	p	200	(a'),(b')	BBν or NBν
6)	p	100	(c'),(d'),(e')	BBν or NBν

*NBν is the NAL Muon Beam No. N1 with the narrow band neutrino beam No. c Phase I first stage and has $\Delta p/p \sim 0.2\%$, $\Delta\Omega \sim 13\ \mu$ strad.

BBν is identical to the NBν beam except the first stage is the NAL broad band ν beam first stage which will be run to have $\Delta p/p \sim 0.2\%$, $\Delta\Omega \sim 10^{-2}\ \mu$ strad.

	Secondary Beam Flux	Primary Proton Beam Configuration† (GeV; particles per pulse from accelerator)	$M^2((\pi^-)^*$ or $(p)^*)$ Range $(GeV)^2$
1)	10^5	200; 10^{12}	0-50
2)	10^5	400; 3×10^{11}	0-100
3)	10^5	200; 10^{12}	0-50
4)	10^5	200; 10^{12}	1-50
5)	10^5	200; 6×10^{11}	1-100
6)	10^5	200; 6×10^{11}	1-50

†This configuration assumes that the primary proton beam's focus at the production target is $1mm^2$ at 400 GeV and $4mm^2$ at 200 GeV. For the π^-'s, flux curves of C. L. Wang (BNL 15893) are used. These curves are considered conservative since the predicted yields are approximately a factor of five lower than the predictions of Trilling. For the π^- beams $1/6 \times (P_p/400)^2$ of the protons are assume to interact in a 1mm x½mm x 1 nuclear free path production target. The proton fluxes used are those given by D. Garelick, Phys. Rev. Lett. 22, 674 (1969).

	$M^2((\pi^-)^*$ or $(P)^*)$ Resolution (fwhm, GeV^2) (single missing mass)	$M^2_{b^o}$ Resolution (fwhm, GeV^2) (double missing mass)	Effective Mass (M_E) Resolution ($\delta M/M$, %, fwhm)
1)	1.0	final state $p\pi^-\pi^o$;0.25	M_E = 0.75; 2%
		" " $pA_2^-b^o$;0.15	M_E = 2.7; 1%
2)	2.0	" " $p\pi^-\pi^o$;0.50	M_E = 0.75; 4%
		" " $pA_2^-b^o$;0.30	M_E = 5.5; 2%
3)	1.0		
4)	1.0	final state $pp\pi^o$;0.25	M_E = 2.7; 1%
		" " $pp\omega^o$;0.25	
5)	2.0	" " $pp\pi^o$;0.50	M_E = 5.5;2%
		" " $pp\omega^o$;0.50	
6)	1.0		M_E = 2.7;1%

	Data Collection Time (hours)	Total Events
1)	200	4×10^6
2)	200	4×10^6
3)	200	4×10^6
4)	200	4×10^6
5)	200	4×10^6
6)	200	4×10^6

TARGET REGION

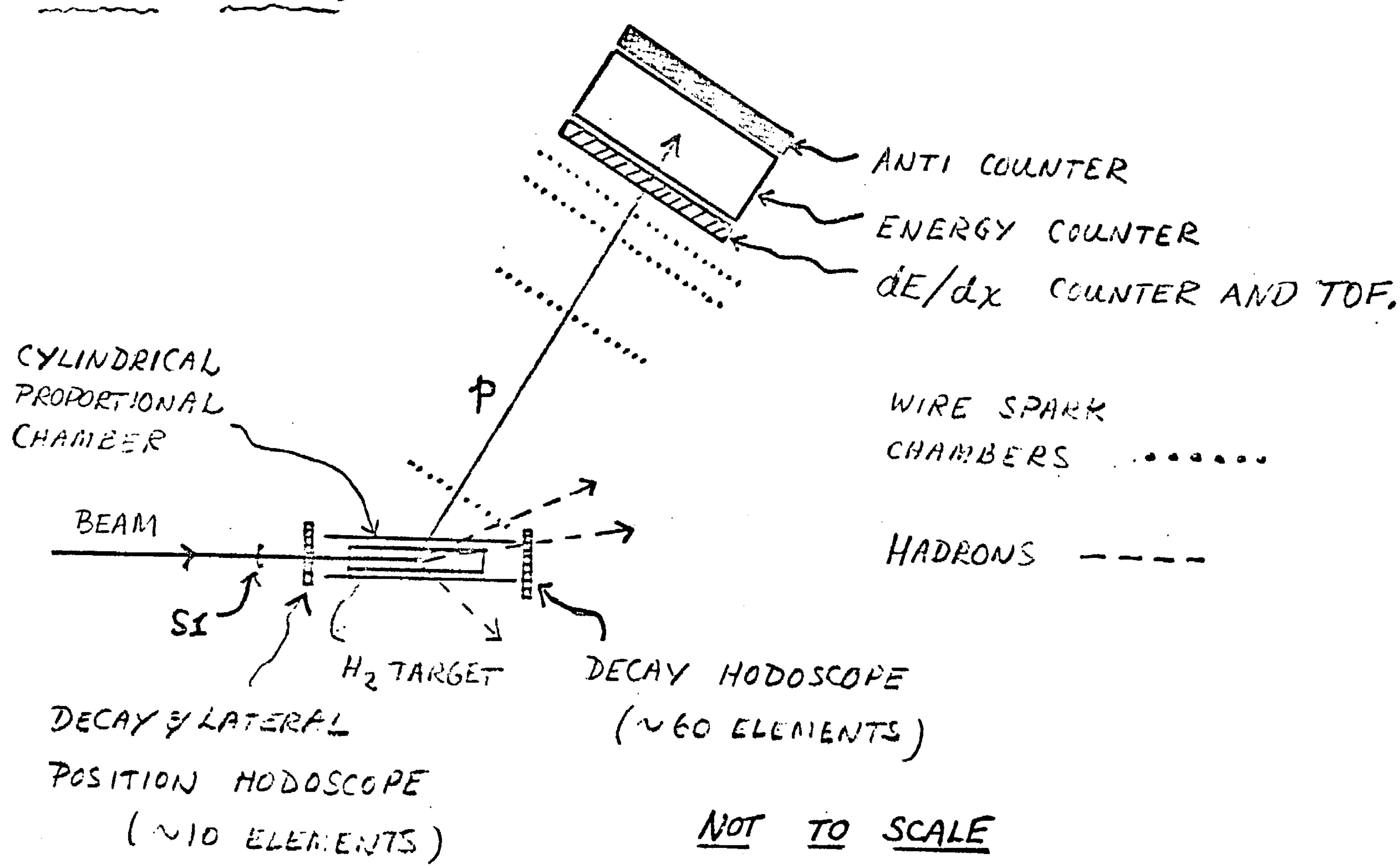
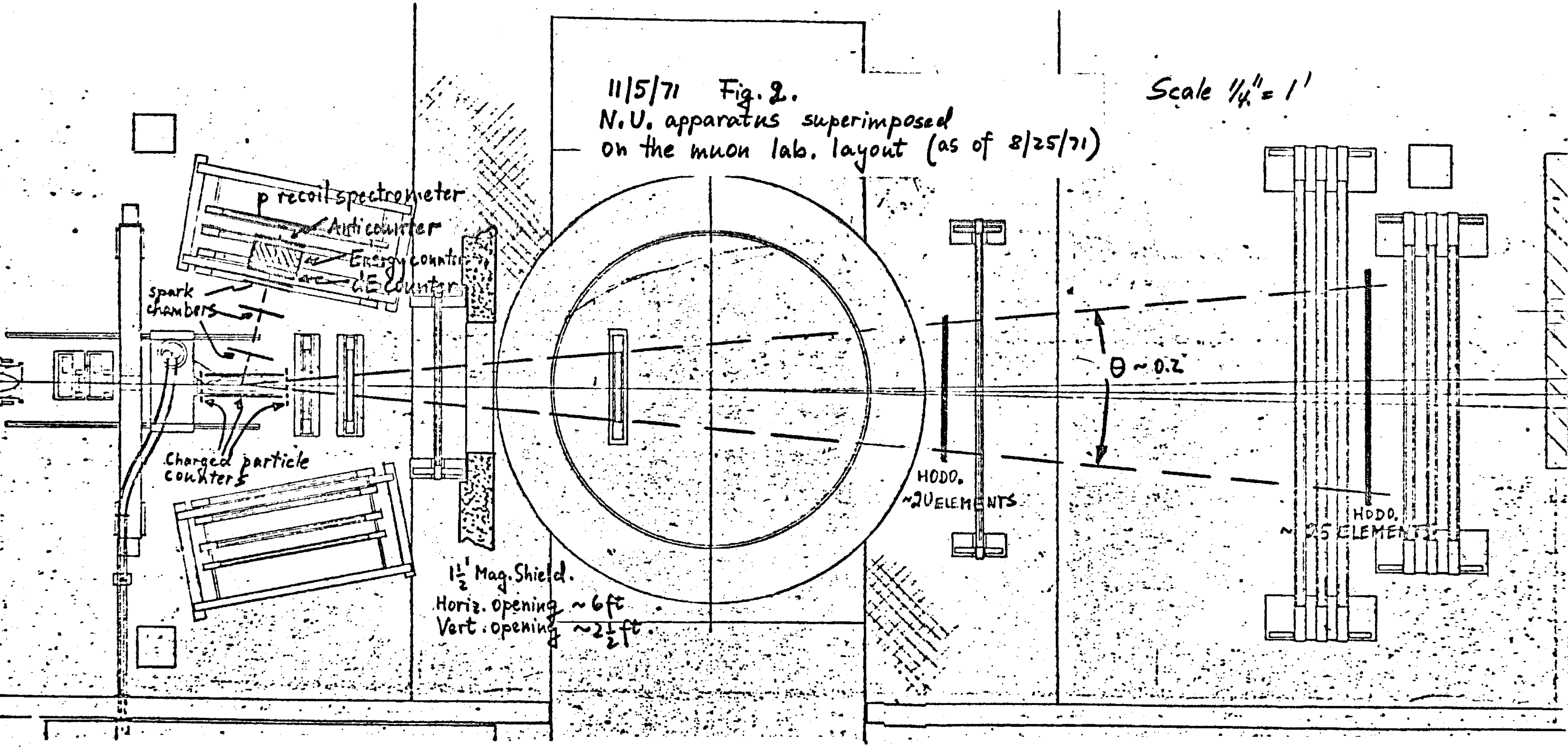


FIG. 1

11/5/71 Fig. 2.
N.U. apparatus superimposed on the muon lab. layout (as of 8/25/71)

Scale 1/4" = 1'



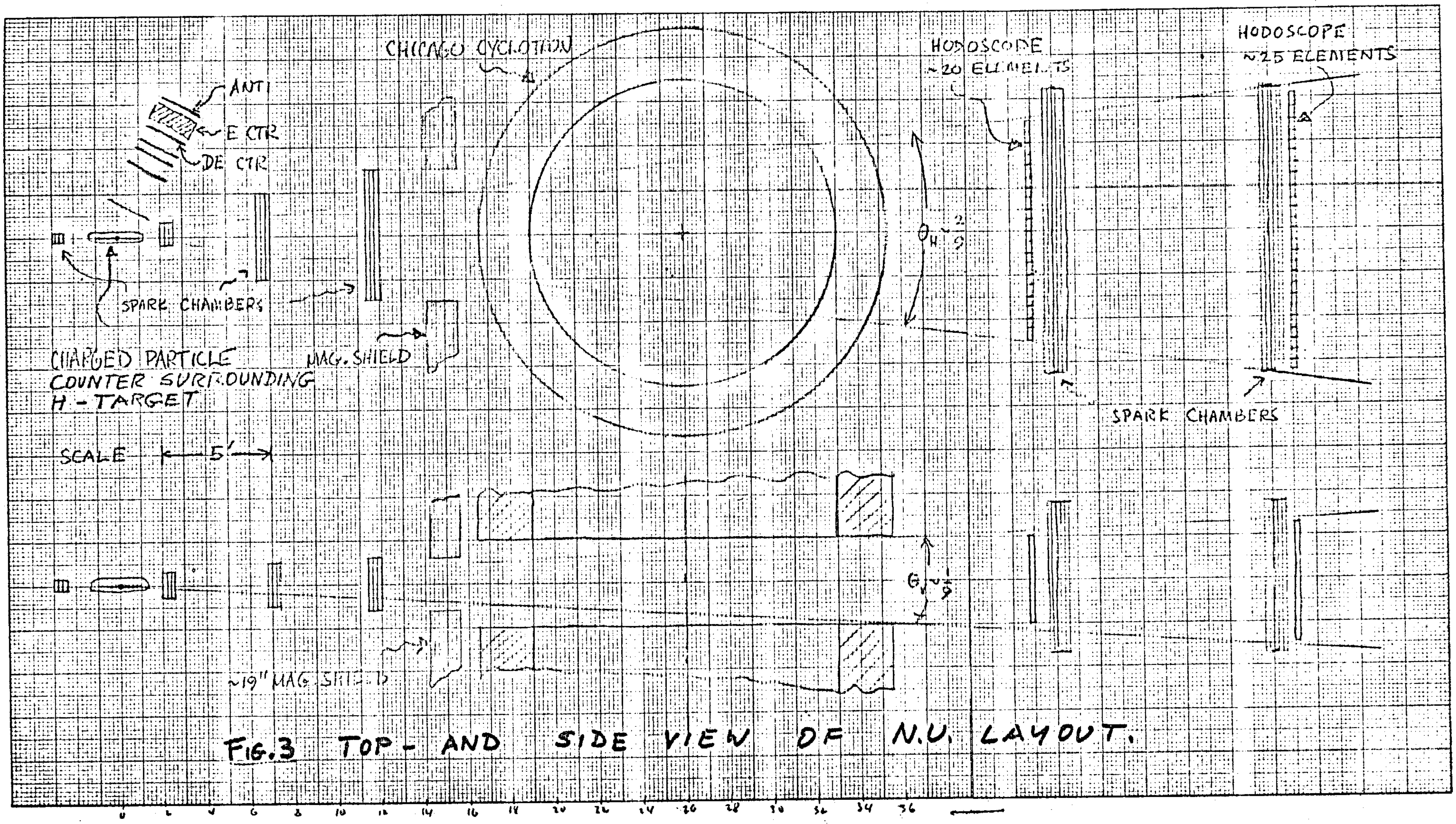


FIG. 3 TOP- AND SIDE VIEW OF N.U. LAYOUT.

NATIONAL ACCELERATOR LABORATORY

P.O. BOX 500
BATAVIA, ILLINOIS 60510
TELEPHONE 312 840-3000

October 15, 1974

Ref: #51A

Professor E. von Goeler
Northeastern University
Physics Department
Boston, Massachusetts 02115

Dear Eb:

I am responding to your recent request for test use of deuterium during the course of the missing mass search associated with Experiment #51A. As you know, this experiment was given a very limited approval of approximately 300 hours to conduct a search using a liquid hydrogen target. The extension you have proposed, to employ liquid deuterium, seems to be a logical extension of your work.

I am approving your request to fill the target with deuterium for a test run during the latter part of your running period due to end on October 23. However, the approval of an additional six weeks of running will have to await, i) a report by you on the results of your test, and ii) some preliminary results from your hydrogen running. If these are available before November 1, I will plan to discuss your extension with the Program Committee at the meeting later that month.

Best wishes for a successful run during this period.

Sincerely,

Jim

James R. Sanford

cc: P. Koehler

PROPOSAL # 51A
~~MASTER~~
~~DO-FILE~~
ELG
~~JRS~~

national accelerator laboratory

February 25, 1975

Dr. Tom Groves, Secretary
Program Advisory Committee

Dear Tom,

Enclosed with this letter is a new proposal for the 15 foot bubble chamber. From Experiment 234 we find that the 15 foot bubble chamber is unique for some hadron physics, that is particularly the study of strange particles and π^0 production. The large fiducial volume of the chamber gives reasonable detection probability for neutral and charge decay of strange particles and for conversion of photons to electron-positron pairs. In comparison with the 30" bubble chamber we find 5 times more events per picture and an order of magnitude higher detection probability for double strangeness or for a photon conversion.

The Fermilab part of this collaboration would like to state a preferance for this new proposal over the approved 30" Experiment 215. We have discussed this with our Berkeley Collaborators and I believe that they prefer film from the 15 foot bubble chamber also (E89 Fretter, E172 Bingham). We believe the small 30" experiments have served their purpose of a rough survey and that it is now time for large experiments.

We hope that the Program Advisory Committee will consider this proposal soon and assuming it is approved, we could start taking film this year. Our collaboration is very anxious to start this physics.

Sincerely yours,

Russ

F. R. Huson

FRH:mlg

Enclosure

PROPOSAL # 384
MASTER
DO FILE
ELG
JRS

national accelerator laboratory

October 22, 1974

To: J. Sanford — Director's Office

From: E. Von Goeler — Experiment 51A

Subject: <u>Extension Request for Present Running Period</u>

This letter is a request to extend our present running period for one week. This will give us a chance to finish our measurements on the reaction $\pi^+, p + p \rightarrow p + X$ at 200 GeV, and therefore essentially complete Experiment 51A.

Let me summarize what we have done so far on Experiment 51A. and what we would still ~~would~~ like to do:

We have completed:

1) Runs on the reaction $\pi^- p \rightarrow p X^-$ at 40, 100, 200, and 240 GeV.

2) Runs on the reaction $\left.\begin{matrix}\pi^+\\ p\end{matrix}\right\} p \rightarrow p X^+$ at 100 GeV.

We have an incomplete run (about 15 per cent of our goal) on the reaction $\pi^+, p + p \rightarrow p + X$ at 200 GeV. This is the run we would complete were we granted the additional one week extension.

Next let me address myself to the deuterium run ~~proposal~~ I proposed in my letter of 10/4/74. We are presently completing a test run on deuterium at two energies: 100^+, and 200^+ GeV. First results look very good as indicated in my report at the experimenters' meeting. I will be able to provide you with more details in about one week.

We elected to do the test run on deuterium since we were under the impression that time for completion of the hydrogen runs could be made available at a later time. Conversations

PROPOSAL # 51A
MASTER
~~DO FILE~~
ELG
JRS

with P. Koehler and A. Green today have brought home the fact that the Laboratory considered the end of the present run the end of Experiment 51A, something that I was totally unaware of and that had not been communicated to us.

In my letter of 10/4 I asked for two additional three week periods. What was not said explicitly in that letter, was the fact that the 6 week extension included two week's running on a proton target since those data are necessary for the deuterium subtraction. Those two weeks were to cover 200 and 40 GeV π^+p data. On reexamination we have decided that the 40 GeV data are not absolutely necessary and can be dropped from the program. We believe that we could complete the program outlined in my letter of 10/4 in one four week period if we could now complete the 200 GeV π^+, p+p run.

I hope that you will be able to grant our request. I will be at the Laboratory until Thursday morning to answer any further questions you may have.

Sincerely,

EvG,

E. Von Goeler
Experiment 51A

EG:mmn

NATIONAL ACCELERATOR LABORATORY
P.O. BOX 500
BATAVIA, ILLINOIS 60510
TELEPHONE 312-840-3000
DIRECTORS OFFICE

October 25, 1974

Ref: #51A

Professor E. Von Goeler
Physics Department
Northeastern University
Boston, Massachusetts 02115

Dear Eb:

I was surprised to receive your request for an extension to your E-51A running. In our conversations and correspondence with you it has been clear that this running period was to be the last. In addition, my letter to you dated October 15 said that tests with deuterium would have to fit into the available time with more running requiring consideration by the Program Advisory Committee. In fact you told me that the tests could be done within the overall time allocated. It is natural that your group is beginning to look for other directions in which to search for gluons, but to compromise your already approved and running experiment for this test strikes me as a case of poor judgment.

After receiving your request we have decided not to extend your run at the present time. I will be prepared to review the matter with the Program Committee. This means that they will consider your request for extended running of π^+ at 200 GeV/c on hydrogen together with the request for six weeks of data-taking with deuterium. In my October 15 letter I stated that consideration of the latter would have to await results from your deuterium test and from your hydrogen running.

I am now suggesting that if you wish to request an extension to your hydrogen running you should justify that, also, on the basis of results obtained to date. If this information is available before November 1, I will plan to bring these matters to the Program Committee Meeting on November 14-16.

Sincerely,

James R. Sanford

PROPOSAL # 51A
MASTER
DO FILE
ELG
JRS

cc: P. Koehler